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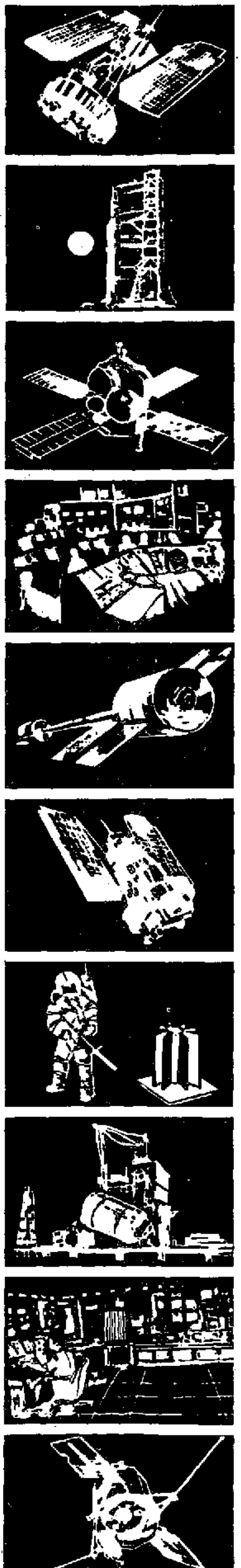

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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

Report No. 3

DESIGN COST TRADE-OFF STUDIES AND RECOMMENDATIONS

EARTH OBSERVATORY SATELLITE

GENERAL ELECTRIC

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EARTH OBSERVATORY SATELLITE SYSTEM DEFINITION STUDY

Report No. 3

DESIGN COST TRADE-OFF STUDIES AND RECOMMENDATIONS

Prepared for:
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Contract No. NAS 5-20518

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TABLE OF CONTENTS

SECTION 1

INTRODUCTION

This report, "Design/Cost Tradeoff Studies," has been prepared for NASA/GSFC under Contract NAS 5-20518, EOS System Definition Study. It presents the results of the significant design/cost tradeoffs made during the first three months of the study and presents summary costs for the total program for selected mission options.

This report is organized into three major cost/trade areas:

- Section 2, System Design/Cost Tradeoffs, discusses those design/cost factors that affect a series of mission/system level questions. This section of the report is organized to correspond to the cost tradeoff matrix presented in the study RFP and expanded in the GE proposal. Many of these system level cost trades are summaries of cost data developed from more detailed subsystem studies and to this extent require lower level trades for substantiation. In a few areas it was preferable to discuss the system trade in its entirety in one place.

- Section 3, Spacecraft Design/Cost Tradeoffs, includes all internal spacecraft and spacecraft interface cost trades. This section is organized around the spacecraft subsystems.

- Section 4, Ground System Design/Cost Tradeoffs, is subdivided into four sections. First, those trades associated with receiving stations and NASCOM facilities; second, those associated with the operations control center and data services elements; third, those affecting the image processing system; and finally, those relating to the low cost ground stations.

- Section 5, Program Cost Summary, provides total program cost estimates of the recurring and non-recurring costs for three mission options.

It should be noted that in Sections 3, 4 and some categories in Section 2, cost trades are made at various levels that may not reflect total program costs. For example, trades of two propulsion subsystem approaches may be made at the subsystem level without regard for "across the board" allocatables, such as program management, etc. However, in Section 5 strict adherence to total cost has been maintained.

Cost data in this volume have been estimated using a variety of techniques depending upon the particular trade being performed. Bottoms-up engineering estimates, supplemented by ROM vender quotes and catalog costs were largely used in Sections 3 and 4. "Similar to" and cost modeling were also used in Sections 2 and 5.

SECTION 2.0
SYSTEM COST TRADES

The RFP contained a comprehensive matrix of cost tradeoff studies for the EOS system. That table was expanded upon by GE in its proposal. All of the cost trades identified in the expanded table have been investigated and are reported in this section.

The order of presentation corresponds to the top line headings in the matrix with one exception; the Spacecraft Autonomy and the Software vs. Hardware trades have been combined under the heading of Spacecraft Autonomy.

For the most part, the contents of this section are summaries of the cost trade results; supporting details are included in the various subsystem discussions in Sections 3 and 4. Where the trade studies are themes of other full Report Volumes, in particular, Orbit and Launch Vehicle and Instruments, only brief discussions have been included. In a few areas, such as Orbit Time of Day, Cost vs. Weight and Volume, and the Shuttle Trades, the topics were addressed in somewhat more detail since corresponding more detailed discussions do not exist elsewhere in the document.

2.1 ORBIT ATTITUDE

The range of altitudes to be considered in these cost trades has been limited to 300 to 500 nm since this is the altitude range of primary interest for EOS-A. Below 300 nm drag causes prohibitive penalties on the ACS and orbit adjust systems, an excessive number of orbit adjusts are required to maintain ground track control and spacecraft to ground transmission time becomes restrictive. Above 500 nm the instrument weights increase excessively and launch vehicle performance becomes limiting.

The cost impacts at three selected altitudes, 300, 400, and 500 nm as a function of subsystem area are identified in Table 2-1. These cost trades are a condensation of the parametric performance analysis presented in Sections 4 and 5 of Report #1, "Orbits/ Launch Vehicle Tradeoff Studies and Recommendations."

Table 2-1. Orbit Altitude Cost Trades

S/S AREA		Impact	Effect of Altitude: 300 NM	400 NM	500 NM
Thematic Mapper		Significant	Lowest cost approach due to minimum size optics and minimum number of detectors if signal-to-noise ratio, ground resolution and swath width are maintained constant.	Pessimestic cost model shows increase of 14%. Weight increase of 15 to 50% depending on type of TM design.	Pessimestic cost model shows increase of 36%. Weight increase of 30 to 130% depending on type of TM design.
HRPI		Significant	Impact on HRPI similar to TM, however cost data is even less definitive. HRPI's also have inverse altitude relationship in that offset angle becomes larger and geometric distortion greater for lower altitudes (i.e., for same access time, lower altitudes require larger offsets and distortions are greater).		
MSS		Significant	Assuming no major modifications to existing design, S/N will decrease with decreasing altitude; many other parameters require evaluation to determine cost impact and altitude limits.		Lowest cost approach
Wideband Communications	240 MBS Link	Minor	Lowest cost approach since "Effective Isotropic Radiated Power" is directly related to orbit altitude.	Same as 500 nm	Cost increase of $34K consists of increased TWT cost of 25K and increased power system cost of 9K. Antenna size remains constant and was selected for 500 nm performance.
	LCU Link	Minor	Lowest cost approach.	Same as 500 nm	Cost increase of $5.0K includes increased tracking cost and increased power system cost.
Mechanical/Thermal		None	Mechanical design not affected by this cost trade. Thermal design not affected by this cost trade since sufficient radiator exists to dissipate power at all altitudes.		
ACS		Minor	At altitudes lower than 350 nm aerodynamic drag becomes significant. An additional 20,000 pole cm capability must be added to the pitch axis magnetic torquer. This gives a weight increase of 6 lbs over 400 and 500 nm and negligible cost impact.	Lowest cost and weight approach.	Lowest cost and weight approach.
SAD		None	The solar array drive is not affected by this cost trade.		
RCS & Orbit Adjust		Minor	No cost variation between options. 50-lb weight penalty for orbit adjust due to higher drag at 300 nm.	No weight penalty due to negligible drag.	
Flight Support System		None	The design and cost of the flight support system and resupply system are independent of orbit altitude. However, the weights of these systems which must be added to the spacecraft weight when considering shuttle delivery, recovery or resupply affect the percent of shuttle total capability used at a given altitude and therefore the shuttle trip charge (this effect is discussed under launch vehicle/propulsion). Minor impact if integral propulsion system returns spacecraft to shuttle orbit ≈300 nm.		
Resupply System		None			
Launch Vehicle Delta Delivery Shuttle Recovery Hydrazine Orbit Transfer (Ref. Report #1 for details)		Significant	No Hydrazine O.T. Lowest cost approach since no orbit transfer propulsion system is required. Allowable S/C weight (minus prop) = 2640 lb	Higher cost approach by 1.5M due to increased shuttle trip charge (larger percent of shuttle capability required). Allowable S/C weight (minus prop) = 2530 lb	Orbit not shuttle compatible and cannot be used without integral propulsion system on spacecraft.
			Hydrazine O.T. System Added to Return to Shuttle @ 300 Not required.	Slightly higher cost approach due to cost of orbit transfer system to return spacecraft to shuttle @ 300 NM (cost delta = 300K NR and 100K recurring). Allowable S/C weight (minus prop) = 2380 lb	Same cost delta as for 400 nm - 300K NR and 100K recurring. Allowable S/C weight (minus prop) = 2000 lb
Solar Array		Minor	Cost penalty of 20K$ due to the increased solar array area required for the lower altitude.	Cost penalty of 6K$ due to the increased solar array area required for the lower altitude.	Lowest cost approach due to combined effects of particle radiation damage and orbital period and dark time.
Electrical Integration		None	Electrical integration is not affected by this cost trade.		
DCS		Minor	FOV of DCS antenna must be sized as a function of altitude. No cost impact. Performance of non-regimented (ERTS like) system will degrade with decreased altitude.		
Ground System		Significant	For direct communications (no TDRS), four ground stations required below 400 nm for US coverage in realtime. Cost impact to equip fourth station with payload unique equipment about $500K.	Three ground stations sufficient	

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The cost swingers are the instruments, launch vehicle and ground station. It is encouraging to note that there are no significant cost impacts in the spacecraft subsystem areas over this altitude range. The cost penalty for equipping a fourth ground station for altitudes in the 300-400 nm region is severe and adds operational complexity and other costs. Even though definitive instrument cost data for TM & HRPI is lacking, clearly their cost will increase with altitude. The 418 nm orbit selected (see Report #1) is just above the altitude where a fourth ground station becomes unnecessary and appears to be a cost effective choice. It also is directly shuttle accessible so that instrument design does not need to change for transition to the shuttle launch system. This selection must be further evaluated for missions involving the MSS.

2.2 LAUNCH VEHICLE OPTIONS

Launch vehicle options are discussed extensively in Report #1. The results show the following:

Candidate Launch System	Spacecraft Weight (lbs) Less Propulsion to 418 nm Altitude	Additional Weight Carried (lbs)	Additional Cost ($M)
Delta 2910	2330	Ref	Ref
Delta 3910	3275	945	2.0
Titan IIIB NUS	4275	1000	6.9

The Delta 2910 is the most cost effective launch system for:

- o EOS-A or EOS-A' including provision for Shuttle retrieval (but not service), including either WBVTR or TDRSS capability for global coverage.
- o EOS-B, including provision for shuttle retrieval (but not service), assuming "light-weight" instruments, and including TDRSS or limited WBVTR capability for global coverage.

The Delta 3910 is the most cost effective launch system for:

- o Combined EOS-A and A', including provision for shuttle retrieval (but not service) and including either WBVTR or TDRSS capability for global coverage.

o EOS-B, including provisions for shuttle retrieval (but not service), and including WBVTR and TDRSS capability for global coverage.

The Titan IIIB NUS is the most cost effective launch system for:

o EOS-B including provision for shuttle service and retrieval, and including WBVTR or TDRSS capability for global coverage.

The new mission definitions are used in the above. Launch vehicle cost impacts are summarized in Table 2-2.

2.3 SHUTTLE/EOS COMPATIBILITY

The basic compatibility of the EOS design with the Shuttle system is covered in many sections of this report and will be considered in detail in Report #6. This section deals with several potential systems compatibility problems which have not been covered at a subsystem level. Only a preliminary cost impact has been made at this time.

		EFFECT					
S/S Area	Impact	DELTA 2910	Launch Sys. Cost (6.6M)	DELTA 3910	Launch Sys. Cost (8.6M)	TITAN III B-NUS	Launch Sys. Cost (15.5M
Structure & Mech.	Minor	light weight		---		heavy weight	
ACS	None	---		---		---	
Power	None	---		---		---	
Solar Array & Drive	Minor	light wt array & less pwr		---		---	
C & DH	Minor	limited redundancy		redundancy		redundancy	
Harness & Signal Cnd	None	---		---		---	
Thermal	None	---		---		---	
Pneumatics	None	---		---		---	
Adapter	Minor	light wt (short adapter)		use existing adapter		new connical adapter req'd	
Orbit Adjust & Orbit Trans	Minor	impact included in launch system costs					
Wideband Commun.	Signif-icant	no tape recorders (HDMR's)		two w.b. tape recorders plus redundancy		two w.b. tape recorders plus redundancy	
MSS	Signif.	limited to one MSS		2 MSS capability		2 MSS capability	
TM	Signif.	limited to 330# instr.		limited to 330# instr.		use any TM	

Table 2-2. Launch System Cost/Performance Impacts

2.3.1 CONTAMINATION

Present designs for the Space Transportation Systems (STS) call for Class 100,000 clean room conditions in the Orbiter payload bay prior to launch. Several nitrogen purges of the bay are planned after the EOS is mated to the Shuttle and the bay doors are closed. There can be no guarantee of any condition, however, approaching the Class 10,000 requirement that is likely to exist for potential EOS mission sensors.

Three alternate approaches to the problem were considered:

1. Sealed EOS - this approach requires either sealing of all EOS joints to eliminate contaminants, or course seals with a purge.
2. EOS Shroud - a special protection shroud would be provided in the Flight Support System (FSS).
3. FSS Shroud - a special protection shroud would be provided in the Flight Support System (FSS).

Preliminary cost impact for the alternative solutions range from a few to several hundred thousand dollars per system.

2.3.2 NETWORK OPERATIONS

The Shuttle Avionics System is designed to accept up to 128 kbps of EOS operational data for real-time and/or store-and-dump transmission to the ground. The data will be interleaved with the Orbiter telemetry and transmitted directly to STDN via an S-band direct PM link. The Orbiter can also accept up to 50 mbps of wideband data for transmission to the ground via a TDRSS Ku-band relay. In either case, EOS data can be separated out at the STDN or TDRSS ground station and transmitted to the EOS mission control center.

In general, this scheme should not present any major problems except for potential delays in the data separation process. Since the Shuttle flight crew is expected to respond autonomously to emergency conditions, the only difficulty may be in issuing commands to modify spacecraft conditions in non-emergency cases. The Orbiter, however, does have the capability to relay commands from the ground to the EOS. The command channel consists of a 2.4 kbps command information rate which is encoded into a 6.4 kbps bit stream prior to transmission to the spacecraft. A 1.6 kbps synchronization pattern is interleaved with the 6.4 kbps encoded rate providing a total command rate of 8 kbps.

The telemetry downlink capability of the Shuttle and the command uplink provisions are fully compatible with EOS requirements. As suggested above, the major potential difficulty is the separation of EOS downlink data from Shuttle data and the retransmission of this data to the appropriate EOS control site. Unless this latter factor becomes a problem, and it is not expected to be, there is no cost impact for providing compatibility in this area.

2.3.3 SAFETY

A preliminary hazards analysis for the EOS design has identified several areas requiring special attention. A complete hazards analysis and identification of required caution and warning monitoring will be contained in Study Report No. 6. The work performed to date has been handicapped by the lack of formal safety requirements and guidelines for Shuttle payloads, however, this data is in a final stage of preparation and is expected to be released by NASA Headquarters shortly.

The preliminary work performed thus far indicates that the following EOS areas could pose hazards to the safety of the Orbiter crew:

1. Hydrazine propellant
2. Premature solar array deployment
3. Electrical power batteries
4. RF Generation

Design efforts have concentrated on severely reducing the likelihood of any condition which would cause harm to a crewman or cause a mission abort. These potential hazard areas are identified, however, to provide traceability for the design features incorporated to reduce their chance of occurrence.

With respect to hydrazine propellant, the potential dangers arise in two areas. First, the possibility of an overpressure condition which could cause propellant leakage or a severe, sudden tank/plumbing rupture (explosion). The danger of this condition is ameliorated by the use of a low pressure system, pressure relief values, and a tank pressure design factor of 2. The second possible hazard arises from the corrosiveness of hydrazine in the event of a leak was to occur within the Orbiter payload bay. The EOS propulsion system has been designed with all weld joints to prevent leaks and redundant valves have been utilized to reduce the likelihood of leaks at the thruster jet or main engine. These are nominal design practices for this subsystem and result in no cost delta for shuttle compatibility in this area.

The premature release of the solar array deployment mechanism could cause difficulty in a number of ways, but the most dangerous appears to be the case which could cause jamming of the payload bay doors in the open position. Another possible danger, release of the array inside the bay and damage to the interior wiring, was discounted due to the soft, low force release mechanism. The danger of premature release, in general, has been reduced by the use of redundant release signals, a separate bus for power to the deployment mechanism, and the use of a remote safe/arm control. Shuttle compatibility results in a cost delta of $8K in the array deployment approach.

Since an overpressure condition in the electrical power batteries is a possibility, two major steps have been taken to insure compatibility with the Shuttle safety requirements. First, the case size used has been maximized for the mission timeline to account for possible contingencies such as pad delays and higher-than-nominal pad temperatures. Second, the battery case structure is designed to reduce the likelihood of external damage should an overpressure condition occur. These design factors have been incorporated at insignificant cost.

The fourth area in which a potential safety problem was identified concerns the inadvertent ignition of Shuttle pyro devices by EOS RF generation. A thorough analysis of EOS/Orbiter EMC has not been conducted due to the limited availability of Orbiter EMC effects and the preliminary state of EOS design. However, the basic EOS design incorporates sufficient shielding to prevent EMI with any of the spacecraft pyros and the potential problem was reduced to an operational one. Major activation of EOS subsystems and use of the telemetry RF link are deferred until the satellite is elevated out of the payload bay. Further the power level output from the telemetry signal is very low and should be incapable of igniting Orbiter pyros.

2.3.4 GROUND/LAUNCH OPERATIONS

Several critical potential problems of EOS/Shuttle compatibility have been evaluated with respect to pre-launch operations. The first of these concerns the requirement for vertical removal of the EOS from a Shuttle on the pad. This requirement has not been considered in depth at this time, although the major factors have been identified. Structural provisions on EOS for this operation would include four attach points for the GSE. Two points would be located adjacent to (and probably integral structurally with) the two upper FSS attach points. The other two GSE attachment points would be located on the docking structure at the aft end of the bus section. The cost of providing these points is minimal, probably adding less than $20K to the vehicle recurring costs. The potential impact on the FSS could be substantial, however. Although not completely clear from the available data, it appears that the four probe and droque interfaces between the EOS and the FSS docking/elevation mechanism require modification for a simple lateral removal of EOS. If the removal activity is to include an axial movement (-x) first, to clear the probes from their EOS seats, then it appears the cradle/EOS interface would require redesign. Estimation of the cost impact of these potential design changes is the responsibility of RI and is not currently available.

A second potential compatibility problem in the ground/launch operations area concerns the EOS test schedule. From KSC's Launch Site Accommodations Handbook for Shuttle Payloads, 2/1/74, the EOS will be installed in the payload bay 80-90 hours before launch. After the payload/Shuttle interface testing is completed, the doors are closed with payload final checkout occurring at approximately 65 hours before launch. Although certain caution and warning and critical function monitoring must be maintained during this time (and throughout ascent), the question of further EOS checkout and testing must be considered.

A review of preliminary EOS checkout requirements has shown that all required, routine spacecraft checkout can be completed prior to L - 80 hours. These are some continuing functions such as battery trickle charging which must be accomplished during this interval but no major checkout activities. If the final payload closeout were to be pushed back beyond L - 100 hours, some cost impact may result.

2.4 THEMATIC MAPPER APPROACH

There are three different approaches to the Thematic Mapper corresponding to each of three different manufacturers: Te Gulton, Hughes and Honeywell. The most fundamental difference between the three is their scanning approach. Many of the tradeoffs throughout the system, particularly in the processing area, are related to the difference in scan technique.

A second major difference between the instrument approaches is their size, weight, and power requirements. The size and weight differences have major impact on the spacecraft configuration and the choice of launch vehicle. Note that only the Hughes version has been weight and volume optimized. A key conclusion is that the other instrument versions must be weight and volume optimized if they are to fly in the planned payload combinations.

A third major difference between the approaches is the availability of existing test equipment, in particular a full aperture radiometric calibration source. This source is by far the most costly of all test equipment.

The impact of the different TM approaches is summarized in Table 2-3. Details of the instrument study results are documented in Volume II of the study reports.

2.5 HRPI APPROACH

There are five different approaches to the High Resolution Pointable Imager instrument corresponding to each of four different manufacturers: Westinghouse with linear and staggered pushbroom array approaches plus three scanning approaches, Te-Gulton,

Table 2.3. TM Approach Cost Tradeoffs

S/S Area	Impact	Te	Hughes	Honeywell
WB Data Handling	Major	If no on-board correction is used, data handling is equivalent between all instrument versions except for data rate. The data rate will result in cost Δ of +10% compared to other two versions. If on-board correction is performed for both LCU & W/B data, the Te instrument is least costly to accommodate.	If no on-board correction is used, cost to implement will be 10% less than Te version. On-board correction of all data requires approximately 10^6 bits of storage because of 2 way scan. Cost over Te to implement is \$150K recurring.	For on-board correction the cost to implement is equivalent to Hughes version. If corrections are applied on-board the cost is approximately equivalent to the Te unit. Data will still be in conical format.
Compactor	Major	If no on-board correction is utilized data compaction cost is equivalent between all instrument versions. If corrections are implemented, the Te approach is the simplest to accommodate.	If no on-board correction is used, data compaction cost is equivalent between all instrument versions. If corrections are implemented, the Hughes cost over the Te approach is \$20K in development and \$45K recurring.	If no on-board correction is utilized, data compaction cost is equivalent between all instrument versions. If corrections are implemented, cost delta over the Te approach is insignificant
Mechanical/ Thermal	Significant	Heavy instrument with weight equivalent to Honeywell. Largest physical size; weight & volume not optimized. Thermal dissipation roughly halfway between Hughes & Honeywell versions. Cost over the Hughes to accommodate is \$50K if weight & volume not reduced to near Hughes equivalent.	Lighest & smallest instrument. Has been design optimized but may be slightly optimistic. Minimum thermal dissipation. Minimum cost to accommodate.	Heaviest instrument. Smaller than Te version but much larger than Hughes. Maximum thermal dissipation; design not optimized. Cost over Hughes to accommodate is \$50K if weight & volume not reduced to near Hughes equivalent.
ACS	None	---	---	---
OBC/Software	Minor	Command/Telemetry requirements similar for all three versions. If on-board processing is utilized, computer algorithms are different for each version but equivalent in cost.	See previous column.	See previous column.
Flight Support	None	---	---	---
Resupply	Minor	Resupply system must be sized to accommodate weight and volume of instruments. Cost varies with these parameters. Delta cost from Hughes is minor.	Lowest resupply cost.	Delta cost from Hughes is minor
GSE	Major	New full field testing device required. Cost delta over Hughes is \$250K. All other GSE equivalent for all approaches.	Existing VSSIR collimator is suitable for full field testing of Hughes TM. All other GSE is equivalent for all approaches.	Existing full field testing device available. All other GSE equivalent for all approaches.
Test Facilities	Minor	Test facility requirements similar for all approaches. Te design may have a windage problem with the roof wheel requiring helium blanket. Need is not clear at this time.	See previous column.	See previous column.
LCRS	Major	Lowest cost data to correct in LCRS.	Adds \$10-25K to LCRS. This is typically 5-10% addition to LCRS hardware cost. Cost is to correct for 2-way and non-linear scan.	Cost equivalent to Te version. Data will be left in conical format with little impact on LCRS or thruput.
CDP	Major	Minimum implementation costs.	Higher cost than Te by \$40K hardware plus programming to process two-way scan data.	Maximum cost impact. Requires \$350K to linearize conical scan data.
LCRS Operations	Minor	Minimum operating cost.	Minor increase in operations/maintenance cost due to small increase in hardware.	Minor increase in operations/maintenance cost due to small increase in hardware. Longer processing time may cause minor increase in personnel requirements.
CDP Operations	Insignificant	Insignificant operations and maintenance cost differences between approaches.	See previous column.	See previous column.
System Engineering	Minor	Different instrument approaches require slightly different engineering during system design. Cost impact is insignificant.	See previous column.	See Previous Column
I&T	Minor	I&T requirements similar for all approaches	See Previous Column	See previous column.
Launch Vehicle	Major	Heavy instrument; cannot be accommodated with a HRPI on Delta launch vehicle. See Launch Vehicle, Section 2.2 for cost impact.	Smallest and lightest instrument, therefore has minimum impact on launch vehicle. Can be flown on Delta 2910 with a HRPI.	Heaviest instrument. Can only be accommodated with a HRPI on Titan Launch Vehicle. See Launch Vehicle, Section 2.2, for cost impact.
Electrical Integration	Minor	All versions have essentially the same electrical interface. No significant cost differences between approaches.	See previous column.	See previous column.
Power	Minor	Power consumption roughly halfway between Hughes & Honeywell versions, but not optimized. Following optimization cost delta will be minor.	Currently lowest power consumption, therefore minimum impact.	Maximum power consumption but not optimized. Following optimization cost delta will be minor.

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Hughes and Honeywell. The three scanning types of HRPI's have the same type of fundamental differences as their TM equivalent as described in the previous section. The Westinghouse approaches, while not scanners, also have the same type of fundamental differences, i.e.,

1. Imaging approach and resultant impact on data processing
2. Size and weight with impact on S/C configuration and launch vehicle (note that only the Hughes version has been size and weight optimized)
3. Test equipment availability

The impact of the four different HRPI approaches is summarized in Table 2-4. Details of the instrument study results are documented in Volume II of the study reports.

2.6 DATA OPERATIONS

Data Operations concerns itself with the method of operating the spacecraft and ground system to acquire, return, process and distribute data that is both useful and timely for users. For the EOS-A mission the general requirements on Data Operation are:

1. Operate the system to obtain global coverage data. Provide maximum coverage with the TM and selected coverage both on and off nadir with HRPI.
2. Obtain all continental U.S. data in real-time.
3. Utilize the WBVTR (or TDRSS) to obtain non-U.S. data.
4. Schedule instrument and WBVTR (TDRSS) data acquisition cycles. Schedule WBVTR playbacks.
5. Schedule operation for local users.
6. Schedule operation for international ground stations.
7. Schedule and control the processing of U.S. data and small percentage of foreign data returned via WBVTR (TDRSS). Assume most foreign data processed/distributed by international ground stations. Scheduling includes process flow and archieving.
8. Coordinate dissemination of products and product information to users. GSFC users include principal investigators plus agencies. Output products include standard products and special orders.
9. Coordinate usage of extractive processing/data analysis facilities.

Table 2-4. HRPI Approach Cost Tradeoffs

Subsystem Area	Impact	Westinghouse	Te	Hughes	Honeywell
Wideband Data Handling	Major	For no on-board correction case, cost will be 10% lower than Hughes due to lower data rate. If on-board processing is implemented, delta costs over Te are: Linear / Staggered NR $150K $150K R $150K $200K	For no on-board storage case, cost delta over Hughes will be +10% due to higher data rate. Te scanning HRPI is the simplest to accommodate if on-board processing is implemented.	Cost to implement without on-board correction is midway between Westinghouse and Te. If on-board processing is implemented the delta cost is $150K recurring over Te version.	Cost to implement without on-board correction is slightly higher than Hughes because of increased data rate. If corrections are applied on board, the cost is approximately equivalent to the Te unit. Data will still be in conical format.
Compactor	Major	For no on-board correction, data compaction costs are equivalent between all instrument versions. If on-board corrections are implemented, the delta costs over Te are: Linear / Staggered NR $80K $80K R $60K $80K	For no on-board correction data compaction costs are equivalent between all instrument versions. If corrections are implemented, the Te approach is the simplest to to accommodate.	For no on-board correction, data compaction costs are equivalent between all instrument versions. If corrections are implemented, the Hughes cost delta over the Te approach is $20K in development cost and $20K recurring.	For no on-board correction, data compaction costs are equivalent between all instrument versions. If corrections are implemented, cost delta over the Te approach is insignificant.
Mechanical/ Thermal	Significant	Much larger and heavier than Hughes. Weight & volume not optimized. Thermal dissipation higher then Hughes. Cost to accommodate is $50K if weight and volume not reduced to near Hughes equivalent.	Maximum weight and size. Not weight & volume optimized. Thermal dissipation same as Westinghouse. Cost delta over Hughes to accommodate is $50K if weight & volume not reduced to near Hughes equivalent.	Lightest and smallest of all versions. Has been design optimized but may be slightly optimistic. Minimum thermal dissipation. Minimum cost to accommodate.	Slightly larger than Westinghouse version but smaller than Te. Weight roughly equivalent to Westinghouse. Thermal dissipation not defined but expected to be highest based on extrapolated TM design. Maximum S/C impact. If not weight & volume optimized cost delta to accommodate over Hughes is $50K.
ACS	None	---	---	---	---
OBC/Software	Minor	Command/Telemetry requirements similar for all four versions.	See previous column.	See previous column.	See previous column.
Flight Support	None	---	---	---	---
Resupply	Minor	Resupply systems must be sized to accommodate weight & volume of instruments. Cost varies with these parameters. Delta cost from Hughes is minor.	Delta cost from Hughes is minor.	Lowest resupply cost.	Delta cost from Hughes is minor.
GSE	Major	New full field testing device required. Cost is a function of instrument aperture size. Westinghouse has largest input aperture. Cost delta over Hughes is $250K. All other GSE equivalent for all approaches.	New full field testing device required. Cost delta over Hughes is $250K. All other GSE equivalent for all approaches.	Existing VSSIR collimator is suitable for full field testing of Hughes instrument. All other GSE is equivalent for all approaches.	Full field testing device available. All other GSE equivalent for all approaches.
Test Facilities	Minor	Test facility requirements similar for all approaches. Te design may have a windage problem with the roof wheel requiring a helium blanket. Need is not clear at this time.			
LCRS	Major	Requires resampling of data on ground. Implementation method demands a sizable memory. Cost delta over Te approach is $30K.	Minimum implementation cost.	Adds $10-25K to cost of LCRS over Te approach or 5-15% addition to LCRS hardware cost. Cost is to correct for 2-way & non-linear scan. Note that if Hughes TM is implemented, the same correction hardware can be used with essentially no cost impact.	Data will be left in conical format with little impact on LCRS cost or thruput.
CDP	Major	Major increase in memory is required to resample the data. Cost delta over Te approach is $185K.	Minimum implementation cost.	Higher cost than Te by $50K hardware plus programming to process 2-way scan data.	Maximum cost impact requires $330K to linearize conical scan data.
	Minor	Minor increase in maintenance cost due to small increase in hardware.	Minimum operating cost.	Minor increase in operations/maintenance cost due to small increase in hardware.	Minor increase in operations/maintenance cost due to small increase in hardware. Longer processing time causes minor increase in requirements.
CDP Operations	Insignificant	Insignificant operations and maintenance cost differences between approaches.			
System Engineering	Minor	Different instrument approaches require slightly different engineering during system design. Cost impact is insignificant.			
I&T	Minor	I&T requirements similar for all approaches			
Launch Vehicle	Major	Heavy instrument in present configuration. Cannot be accommodated with a TM on a Delta 2910 vehicle without size & weight optimization See Launch Vehicle, Section 2.2, for cost impact.		Lowest weight & volume. Can be accommodated on Delta 2910 with a light weight (Hughes) TM. Minimum impact on launch vehicle.	Same as first column.
Electrical Integration	Minor	All versions have essentially the same electrical interface. No significant cost difference between approaches.			
Power	Minor	Power consumption roughly halfway between Hughes & Honeywell but not optimized. Power subsystem cost delta over Hughes is expected to be minor after optimization.	Similar to Westinghouse	Currently, lowest power consumption because of optimization, there therefore, minimum impact.	Same as Westinghouse.

These requirements are all related to one or more of the following:

1. Number of users
2. System throughput
3. Number of output products

The cost of satisfying the requirements are all a function of one or more of these three variables. These variables, in turn, reflect themselves in costs of various subsystem and operations areas. These relationships are summarized in Table 2-5 and their cost impacts discussed in the sections noted.

The CDP equipment, its operation and expendables are the most severely impacted by those variables. The following shows the impact on just the IPS equipment costs as an indicator of its sensitivity to these variables. A complete analysis is given in Section 4.3.

IPS Equipment	40 Scenes per Day	250 Scenes per Day
Image Correction Subsystem	$2.2 M	$3.1 M
HDDT Generation	.1	.4
CCT Generation	.3	.5
Film Generation	.7	2.7
	$3.3 M	$6.7 M

2.7 SPACECRAFT AUTONOMY

A complete set of system level trades have been performed to

1. Define all functions which could potentially be performed by the OBC
2. Assess the cost and performance impact of OBC vs. subsystem hardware implementation.
3. Where software was most cost effective, assess the cost and performance impact of implementing the function in the OBC vs. on the ground.

This tradeoff resulted in preliminary assessments of processing load and memory requirements for the OBC as summarized in Table 2-6. The loading and memory requirements

Table 2-5. Data Operation Cost Tradeoffs

SUBSYSTEM AREA	IMPACT	EFFECT f (Number of Users)	f (Thruput)	f (Number, Type of Output Product)
OBC Software	Minor	Command capability to operate spacecraft to satisfy wide range of numbers or geographic distributions of users, is in the noise of OBC requirements. Once the system is designed to acquire data over a single area such as a ground station, the delta capability to acquire data over many ground stations is measured in tens of words of OBC memory.	No effect for ranges of thruput considered for EOS-A. Minor effect if OBC is to support the addition of ancillary data or on-board data correction in MOMS. This effect costed under Spacecraft Autonomy.	None
LCRS	Major	Large number of low cost users imply implementing correction techniques on-board the spacecraft. This is a major trade area and is considered under S/C vs Ground Function.	Thruput is directly related to LCRS cost of hardware/software and processing time (hence cost of people). This impact is considered under LCRS, Section 4.4.	Cost is directly related to number, type of products and radiometric/geometric corrections implemented in LCRS. This impact is considered under LCRS.
Compactor/MOMS	Major	Large numbers of low-cost users imply implementing correction techniques on-board the spacecraft. Implementation would be performed in the compactor. Cost trade is described under S/C vs Ground Function.	None	None
Control Center/Control Center Ops	Minor	Control center must schedule S/C and network operations. Cost of scheduling and control is only slightly related to the number of users (provided users have their data processed at the CDPF). Many low cost or international users will require coordination with OCC for calibration data, S/C time updates, etc. Cost delta for multistation support is 1 man, 1 shift per day over the life of the S/C.	Insignificant	None
Network Ops	Minor	None	Increased thruput requires increased S/C contact time to return the data which in turn requires more support from the network. Cost is related primarily to RT only/WBVTR/TDRSS approach	None
CDP	Major	Number of users translates directly into number of output products, hence impact is on reproduction facilities. See Section 4.3.	CDP system design approach and cost is directly related to thruput. Comprehensive discussion of cost relationship for CDP is included in Section 4.3.	Reproduction facilities directly related to number of users and type of products. See Section 4.3.
CDP Ops	Major	Number of users supported is directly related to the number of people required in the CDP Facility for support.	Operation of CDP is directly related to system design approach which is driven by thruput.	Number and type of output products is a key element in determining the reproduction, shipping and liaison manpower required in the CDP Facility.
CDP Expendables	Major	Number of users, quantities and types of output products largely determine expendables cost in the CDP facility. These costs are substantial. For example, annual expendables for photographic materials for ERTS-1 is about $2.4M.	Minor effect compared to effect of number of users and output products. See previous column.	See first column.

were utilized to evaluate the application of the AOP plus make recommendations on improvements to increase overall AOP processing capability as described in Section 3.2.

The left side of the table indicates areas where the OBC can cost-effectively provide computational support. The subsystems required evaluation at the sub-function level to determine the optimum division of functions between OBC, spacecraft hardware, and ground computation. In many cases, a combination of all three is the preferred approach. A good example is telemetry processing with an implementation approach of selected OBC telemetry data processing, telemetry formatting via subsystem hardware plus data analysis on the ground. Other functions such as antenna pointing computations can effectively be implemented entirely by ground and OBC software. Recommended implementation approaches are summarized in Table 2-7. A complete description of the selected approach will be provided in Report 5.

Table 2-6. AOP Loading Summary

Function	DELTA CPU Usage (%)		DELTA Memory (K Words)		DELTA Power (watts)		DELTA Weight (lbs)		DELTA Volume (in^3)		DELTA Cost (K$) Recurring		DELTA Cost (K$) Nonrecurring	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Baseline AOP 1 CPU-I/O; 1 8K Memory 1 Pwr Conv; 1 Pwr Switch	3.0	5.0	8.0	8.0	20.3	20.3	20.0	20.0	40.3	40.3	155	155	12.0	12.0
Total Telemetry	1.6	16.7	2.0	7.4	2.0	8.0	3.0	11.1	60.5	235.8	5.9	22.1	24.0	56.0
Total Command	5.0	5.0	2.8	2.8	2.9	2.9	4.2	4.2	86.6	86.6	8.3	8.3	28.0	28.0
Total Power	0.1	0.3	0.4	0.8	0.4	0.8	0.5	1.2	11.7	23.2	1.1	2.1	5.3	5.3
Total Thermal	0.01	0.02	0.3	0.3	0.3	0.3	0.5	0.5	9.5	9.8	0.9	1.0	4.6	4.6
Total Antenna Pointing	1.2	12.0	6.5	6.5	6.7	6.7	9.7	9.7	206.1	206.1	19.3	19.3	48.0	48.0
Total Performance Monitoring	2.8	5.2	3.4	4.6	3.5	4.7	5.0	6.8	110.4	145.6	10.1	13.7	26.0	26.0
Total ACS	24.7 Inst 17.4 Avg	36.0 Inst 29.0 Avg	3.4	6.8	3.5	7.0	5.1	10.1	107.9	216.2	10.1	20.2	36.0	36.0
Total Payload	0.01	0.01	1.6	1.6	1.6	1.6	2.4	2.4	50.0	50.0	4.7	4.7	9.2	9.2
Total Propulsion	0.4	0.4	0.5	0.5	0.5	0.5	0.8	0.8	16.0	16.0	0.9	0.9	12.0	12.0
Total All Systems	36.0 Inst 28.5 Avg	76.0 Inst 68.6 Avg	20.9	31.3	21.4	32.5	31.2	46.8	658.7	989.3	61.3	92.3	193.1	225.1
Total All Systems + AOP	39.0 Inst 31.5 Avg	81.0 Inst 73.6 Avg	28.9	39.3	41.7	52.8	51.2	66.8	1061.7	1392.3	216.3	247.3	205.1	237.1

Table 2-7. OBC/Subsystem Hardware/Ground Processing Implementation Approach.

	OBC	S/C Hardware	Ground Processing
Telemetry			
Format Control	X	X	
Limit Checking (All Subsystems)	X		X
Status Checks (All Subsystems)	X		X
Alarm Checks (All Subsystems)	X		X
Command			
Decoding and Execution		X	
Delayed Cmd Processing	X		
Special Cmd Generation	X		
Power			
Load V/I Limit Monitoring	X		
Load Pwr Consumption Monitoring	X		
Battery Chg/Discharge Monitoring	X		Periodic
Battery Operating Point Control	X		Monitoring
Battery Thermal Profile Monitoring	X		
Load Configuration Control	X		
Self-Test	X		
Diagnostics	X		
Thermal/Structure			
Compensation Heater Control	X		
Thermal Monitor	X		Periodic
Self Test	X		Monitoring
Diagnostic	X		
Alarm, Perf. Monitoring, Sys. Test			
Processor Self Test	X		
S/C System Self Test	X		Periodic
Go/No Go Limit Processor	X		Monitoring
Perf. and Environ. Monitoring	X		
Caution & Warning Processor	X		
Diagnostic & Repair Verification			X
Test Eval. & Historical Trends			X
S/C Operating Signature			X
ACS (All Functions)	X		
Antenna Pointing	X		
Payload			Periodic
Mode Selection (P/L & MOMS)	X		Monitoring
HRPI Pointing	X		
Correction Function Computation	X		
Ancillary Data Insertion	X		
Propulsion			
Orbit Adjust/Transfer Monitor	X		

2.8 ELECTRONIC TECHNOLOGY

The present conceptual design of EOS incorporates conventional design techniques in most areas. This was done to keep non-recurring costs as low as possible with state of the art techniques being used only in areas dictated by size, weight, power, or functional requirements. Two areas of design which are significantly influenced by electronic technology are discussed below. Two others, the potential of CCD's for instrument detectors (Report #1) and consideration of GaAs devices for direct high power level modulation (Section 3, 4 of this report), have already been discussed elsewhere.

Command and Telemetry Remotes. The data bus can support up to 32 remote units. The large number of these remotes and the fact that they consume volume, weight, and power in each spacecraft module make it desirable to minimize their size, weight and power requirements. Reasonable size (40 in^3) and weight (1.5 lbs) can be achieved with conventional techniques, but minimum power requires use of more efficient design (power strobing) and components (low power TTL, CMOS). In general, an order of magnitude power savings can be achieved in using low power TTL vs. conventional TTL at a cost increase of about 20%. CMOS offers about two orders of magnitude savings in power at 100% increase in cost. At present, low power A/D convertors do not appear to be available, but could be in the time frame of EOS. Use of low power TTL or CMOS would require some additional interface circuitry to provide adequate power to drive the data bus. CMOS requires less power regulation and offers more noise immunity, but is more susceptable to radiation levels above 10,000 rads.

OBC Memory Design. The three basic memory technologies considered for the EOS are plated wire, core, and semiconductor.

Both core and plated wire are non-volatile (i.e., retain contents during loss of power) whereas the semiconductor memory is volatile. Plated wire memory consumes, in the operating mode, significantly less power than core memory - approximately 5 watts vs. 35 watts for 4,096 words of 18 bits each. Also plated wire occupies less volume and weighs less - 100 cubic inches and 4 lbs vs. 128 cubic inches and 6 lbs for the memory size cited above. The speed of these two memory types is essentially the same - about 750 microseconds access time and 2 microseconds cycle time. The reliability of plated wire memory is considerably higher than that of core - a MTBF of 90,000 hours vs. the MTBF of 40,000 hours. The above comparisons are based upon use of a 5 mil diameter plated wire 2D stack and 20 mil diameter cores 2-1/2 D stack. It is evident from the above discussion that a plated wire memory approach is definitely superior to the core approach from a performance standpoint. However, after years of experience in the experimental development and production of plated wire memories, it appears that yield from this technology is quite poor resulting in a much higher cost than that for core memories. The cost per bit of plated wire memory is estimated at $0.50 as contrasted with $0.12 for core memory.

For a spacecraft fabricated/assembled in the 1976-77 time frame and flown in the 1979 time frame, it is felt that semiconductor memory would be the most logical choice. Rapid progress is being made in the development of LSI and hybrid LSI memories, particuarly in theC-MOS area. C-MOS LSI circuits have already been space qualified and it appears quite probable that within the next couple of years, memories comprised of C-MOS LSI arrays will be cost competitive with core memories. A C-MOS LSI memory of the capacity cited above would be approximately half the size and half the weight of a plated wire memory. The operating power of a C-MOS LSI would be an order of magnitude lower than the plated wire memory, permitting an inexpensive additional on-board power supply to compensate for the volatibility of the semiconductor memory if, indeed, the volatibility issue is an important one. (If the spacecraft power system fails, what benefit derives from retaining the contents of the OBC memory? During a recovery procedure - implemented either by ground commands or shuttle in-orbit maintenance - the semiconductor memory could be reloaded. The access time of a semiconductor memory would be somewhat faster than that of a plated wire memory but the cycle time would be twice as fast. The reliability of a semiconductor memory would be somewhat better than the plated wire memory.

2.9 ORBIT TIME OF DAY

The choice of orbit time of day affects both system costs and user satisfaction and benefit. Involved in the choice are considerations of: (a) expected radiance levels; (b) expected cloud cover and other atmospheric error-inducing phenomena; and (c) the utility of measurements in each of the spectral regions (visible, near IR, thermal IR) at varying times.

2.9.1 REQUIREMENTS

User Requirements. GE's TERSSE study results show that user needs for data which are affected by orbit time of day may be classified into two categories: (a) no special time requirement (the bulk of the users); or (b) specific time requirements. Of the latter, greater than 50% require near-noon measurements, with the remainder being scattered over predawn, mid-morning, mid-afternoon, and late evening. (It should be noted that some missions require measurements at multiple times of day and are thus precluded from being served by a single sun-synchronous satellite.)

Both the users with no special time requirements and those requiring mid-day measurements are best served by a near-noon orbit time. Since these users together comprise nearly 75% of the total, and since no other single time of day can satisfy such a high percentage of users, the conclusion is reached that a mid-day orbit is the best choice from a user requirement standpoint.

Radiance Effects. The scene irradiance is dominated in the visible and near-IR spectral regions by the solar illumination (which is a function of season, latitude, time of day) and scene reflectivity. Sensor signal-to-noise performance, for a given cost, is a positive function of scene irradiance. And, since nearly all user requirements are better satisfied with increasing signal-to-noise performance, sensor cost and scene irradiance levels are tradeable parameters. On one hand the sensor S/N performance may be increased by larger optics, higher quality detectors, or cooling; on the other hand, S/N performance may be increased by an orbit with higher inherit scene irradiance (e.g., near mid-day). It is obvious that when scene radiance is considered in the absence of other relationships, mid-day orbit times are desirable.

A second radiance related effect is the "hot spot", or secular component of reflected sunlight. The hot spot location is such that it occurs in the image quite frequently in a mid-day orbit. Since correction of the data to remove this effect is costly, if possible at all, the effect should be pre-empted by offsetting the time of day to either side of noon an appropriate amount depending on the swath-width.

Clouds/Haze. The intervening atmosphere presents an obstacle to mission fulfillment which is only partially solvable by system design. In any real system, the clouds/haze problem solution will be a statistical one, with probabilities of mission success weighed against cost of alternative approaches and the probabilities of clouds/haze existence. The latter probabilities are somewhat controllable by selection of the orbit time of day, as most regions of the globe exhibit diurnal variations of clouds/haze conditions. Since the previous discussion pointed to a desire for near-mid-day orbits, the clouds/haze variable should be considered in the context of its altering of the mid-day choice.

No concrete indisputable answers exist concerning Macro and microscale meteorology. It is fair to state, however, that forenoon clouds/haze are less debilitating than afternoon. Thus, if the previous choice of mid-day is to be altered, it should be done in the direction of earlier orbit times, rather than later.

In summary, the mid-day orbit is desirable from the standpoint of user satisfaction and sensor S/N performance. It should be offset to one side or the other of mid-day to reduce the costs of "hot spot" processing and increase data utility. And finally, it should be offset to the forenoon side to increase the overall probability of cloud free imaging.

2.9.2 IMPACT ON SUBSYSTEMS

The impact of varying orbit time of day is summarized in Table 2-8. Note there are no significant impacts over the range of orbits from 9:00 AM to 2:30 PM which bracket all realistic times for the EOS-A Land Resource Management Mission. The primary impact areas are in the instrument where sufficient input radiance is required to insure adequate S/N performance.

Table 2-8. Orbit Time of Day Cost Trades

S/S Area	Impact	Description
TM	Significant	Higher sun angles, corresponding to sun synchronous orbits nearer to noon, provide increasing scene radiance, hence improved signal to noise performance. Cost of sensor performance is directly related to orbit time of day with the best performance at or near noon. Orbits very near noon exhibit sun glint or "hot spot" effects. This effect is a function of orbit time of day and sensor field of view. For orbit times of 11:30 and earlier, or 12:30 and later, it is not a problem. From an instrument point of view 11:30 or 12:30 are preferred.
HRPI	Significant	Similar to TM above.
Mechanical/ Thermal	Minor	The effect is twofold: the thermal dissipation of the spacecraft, and the mounting of instruments such that the coolers do not view the sun. While both of these considerations have minor impact on the detailed design of the spacecraft, they have insignificant impact on cost.
ACS	Minor	Affected only in the area of star sensing. Star sensors are disabled by sunlight and operate only beyond some minimum angle from the sun. For sun synchronous orbits which maintain a fixed relationship with respect to the sun, a shield about the star sensor will prevent the sun from entering. For the range of times considered for EOS-A, sun shields are not required since the sun never illuminates the exit port of the star sensor.
Solar Array	Minor	For a given spacecraft energy power level, solar array area is a function of orbit time of day. Ideally, the preferred orbit time of day from a power standpoint is 6 AM permitting full sun illumination and fixed solar arrays. Since this is not in the realistic range of consideration for the EOS-A mission, it was not considered to be a fair reference point for cost trade. Over the range of EOS-A orbit times from 9:00 AM to 2:30 PM the array cost varies by only 48K. The cost penalty for an 11:30 AM orbit is minor.
Pneumatics/ Orbit Adjust	None	

2.9.3 CONCLUSION

The preferred orbit time of day is near but prior to noon with 11:30 AM the recommended time.

2.10 MANAGEMENT APPROACH

The study has shown that specific cost trades of Management Approaches against the various areas indicated in the cost trade matrix of the RFP could not be made in the strict sense. These management functions are non-allocable cost areas since at the level these functions are performed, any allocation of cost or cost deltas to hardware components or other system elements would be strictly arbitrary and could not be justified as a fair and applicable cost. Therefore, cost deltas for one approach versus another in any of these functional areas could not be allocated for cost trade purposes against hardware components.

The Low Cost Management Approaches presented in Report #4 are nevertheless aimed at achieving minimum overall program cost. That it is difficult to quanfiy their cost impact does not diminish their importance.

2.11 TEST PHILOSOPHY

The unique aspects of the EOS design approach have been thoroughly studied and compared to programs now in progress or recently completed. This study led to a viable test philosophy and program that could be effectively implemented in two steps. The first step moves from the present approach to the EOS-A program and the second step carries the cost reduction techniques even further for additional savings in the follow-on spacecraft test programs. (Refer to Report #4 for a discussion of this test program approach).

Prime considerations were given to the effects of multiple missions utilizing identical spacecraft bus hardware, fully modular design, on-orbit repair by replacing subsystem modules, on-board computer utilization for test and trouble-shooting, and reducing the effort expended on various spacecraft models as the overall program progresses through several spacecraft.

Figure 2-1 shows a summary test flow of the recommended approach compared with a "business as usual" approach. Table 2-9 shows the degree of tests performed in each area, including spacecraft models considered for each test program. A summary of the comparative costs are provided in Table 2-10. This clearly shows the net reduction in total test costs as the program progresses. This is primarily achieved by the reduction of required test models and the reduction of large test crews required for long, full system level test programs. These costs do not consider the impact of reduced hardware. Only one full set of prime spacecraft hardware (plus desired spares) is required for the recommended development and flight program for either A or A'. Nearly two sets are required for the "business as usual" approach.

Since the EOS program will be a multiple vehicle program utilizing the same basic subsystem modules and structure for each spacecraft, it is uniquely suited for such an approach. The subsystem modular concept also lends itself to this philosophy. Subsystem environ-

Table 2-9. Test Program

	Business As Usual	Low Cost Approach	
	Typical S/C	EOS-A	Follow-On EOS
S/C Models			
Thermal	Yes	No	No
SDM	Yes	Yes	As Required
Antenna	Yes	As Required	As Required
Harness M/U	Yes	Yes	As Required
Component			
Qualification			
Elec. Perf.	Yes	Yes	No
Mechanical	Yes	Partial	No
Environmental	Yes	Partial	No
Flight			
Elec. Perf.	Yes	Yes**	Yes
Mechanical	Yes	Partial	Partial
Environmental	Yes	Partial	Partial
Subsystem or Module			
Qualification			
Elec. Perf.	No	Yes	No
Mechanical	No	Yes	No
Environmental	No	Yes	No
Flight			
Elec. Perf.	Yes	No*	Yes
Mechanical	No	No*	Yes
Environmental	No	No*	Yes
System			
Bit	No	Yes	As Required
Prototype S/C	Yes	No	No
Proto-Flight			
Elec. Perf.	No	Yes	No
Mechanical	No	Yes	No
Environmental	No	Yes	No
Flight			
Elec. Perf.	Yes	No*	Yes
Mechanical	Yes	No*	Yes
Environmental	Yes	No*	No

* Qual unit(s)/Subsystem(s) used for flight
** Additional unit(s) needed where qual units not available

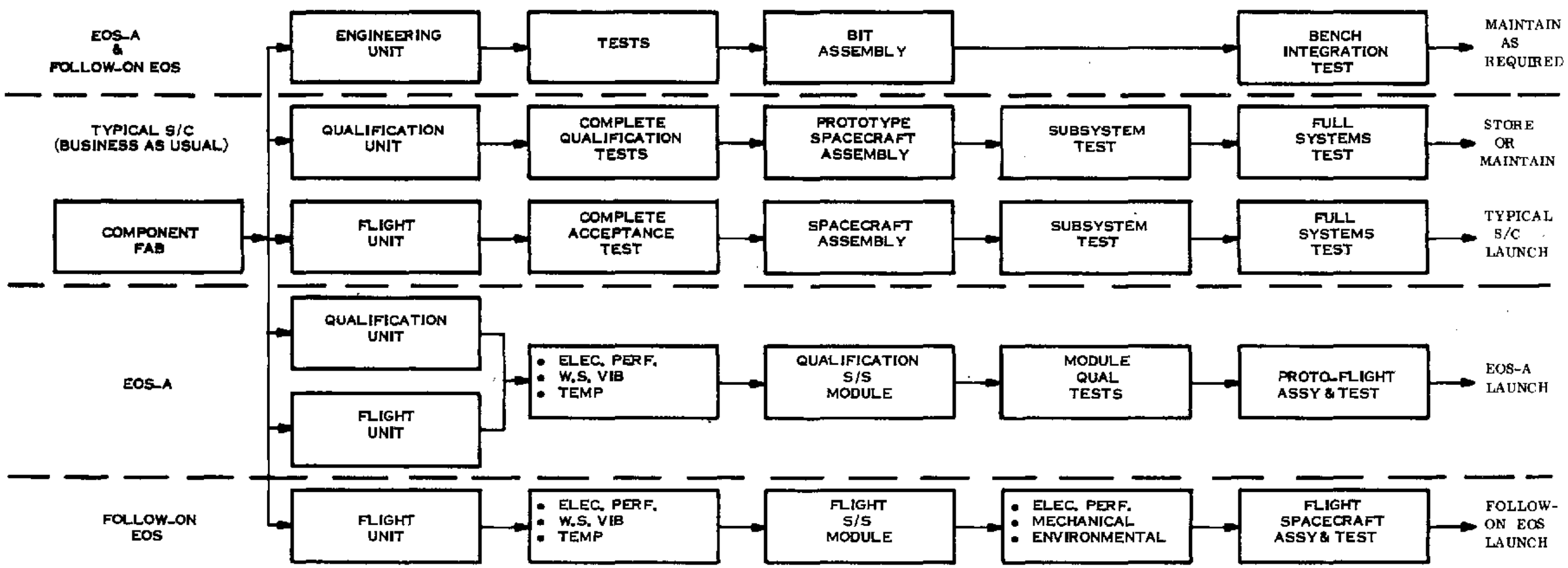

Figure 2-1. Summary Test Flow

Table 2-10. Estimated Test Costs

	Business as Usual	Low Cost Approach EOS-A	Low Cost Approach Follow-On EOS
S/C Models	$980K (24%)	$510K (19%)	$180K (15%)
Component	$920K (23%)	$430K (16%)	$430K (35%)
Subsystem or Module	$ 72K (2%)	$144K (5%)	$144K (12%)
System	$2100K (51%)	$1550K (60%)	$460K (38%)
Totals	$4072K	$2634K	$1214K
Cost Savings	←1438K→	←1420K→	
	←2858K→		

(Numbers in parenthesis = percentage of total test cost.)

mental testing at the module level can be made as fully stringent and realistic as at the spacecraft level. Further, any subsequent module replacement due to malfunction or failure during systems testing can be made with minimum impact on the spacecraft test program because environmental testing has already taken place.

2.12 RELIABILITY AND QUALITY ASSURANCE REQUIREMENTS

The cost trades in this section are related entirely to the cost of redundancy for reliability. Quality Assurance is a non-allocable cost, hence viable cost trade data would be rather artificial and difficult to substantiate.

Two aspects of redundancy were considered: (1) redundancy necessary to assure reliable operation of the spacecraft such that no single failure would impare full mission success; and (2) redundancy necessary to survive any single failure for subsequent Shuttle servicing/ retrieval. The latter approach has been provided in the spacecraft basic design.

The cost and justification of this level of redundancy is summarized in Table 2-11. The table shows the redundancy approach costs nearly 3/4 of a million if the selected mission peculiar redundancy is included.

Additional details on each of redundancy cost trades may be found in the applicable sections of this report.

2.13 COMMONALITY POTENTIAL

A basic objective of the EOS Study is to provide a design for a general purpose spacecraft with sufficient flexibility to accommodate the EOS-A mission requirements as well as a number of follow-on mission payloads. The general approach during the study was to establish the driving requirements for each subsystem and to provide a design for those subsystems which could indeed allow them to be utilized for various missions. Each subsystem was investigated in Section 3 of this report. In addition, Section 2.15, "Follow-On Instrument Accommodation" has been generalized to include commonality effects and the cost impact of a general purpose spacecraft are summarized therein. This section will summarize the overall results of these individual studies in terms of providing a listing of the common hardware items and the number of units to permit a "low cost" multiple buy approach. It is predicated upon the original mission model.

2.13.1 MISSION MODEL

The mission model used in the study is presented below:

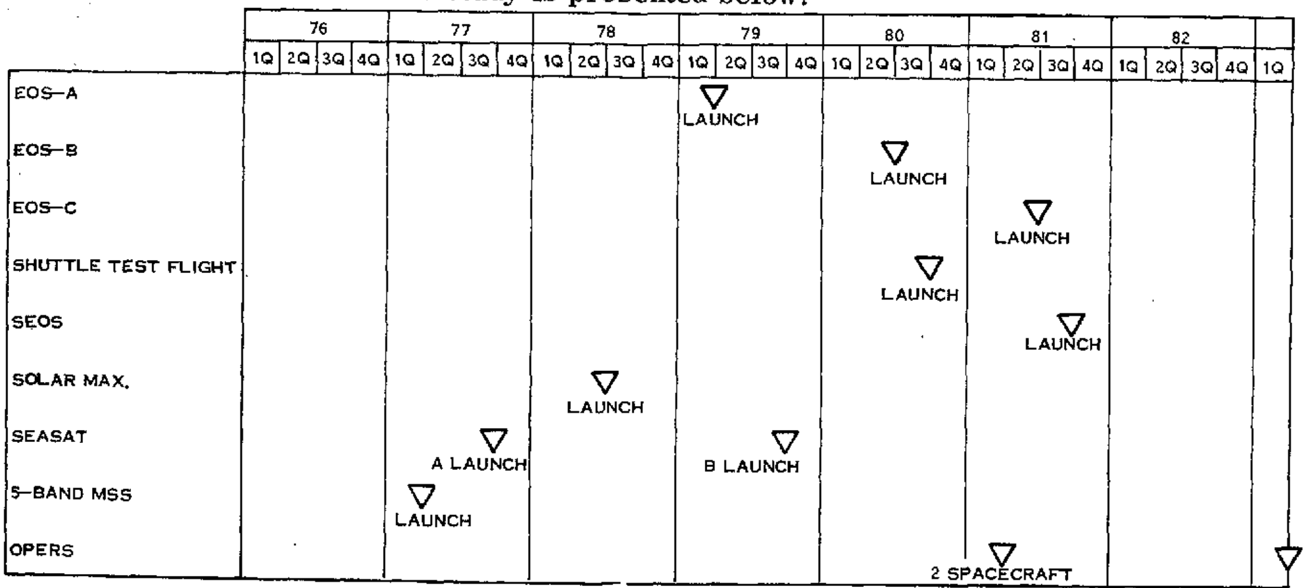

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Table 2-11. Reliability/Redundancy Cost Tradeoffs

SUBSYSTEM	REASON	DESIGN/COST IMPACT	COMMENTS
Command & Data Handling			
Command Link	Transponder, command demod., central command decoder and clock-redundant link assures command capability for retrieval.	Minimum of 3 watts, 27 pounds, and $170K recurring cost.	The alternative is a fully redundant C&DH with impact of 6 watts, 97 pounds, and $595K recurring cost.
Data Busses & Remotes	Required for partyline technique. Also used with redundant command link.	See Above	
On-Board Computer	Redundant CPU-reliability of operations, data handling	4 lbs, 5 watts & $60K	Redundancy is highly recommended since CPU vital to all mission operations.
Propulsion			
Main Engine	Redundant main engine-required for orbit transfer.	$30K	No redundant engine would require shuttle retrieve at mission altitude in event of engine failure; a significant cost.
Mechanisms			
Solar Array Drive	Redundant motors and gear train-risk would be unreasonably high not to be redundant.	$4K	Past history supports recommendation for redundancy.
MSS-Tape Recorders	Redundant tape recorders-operational life of recorder is less than planned mission life.	$410K	Required to demonstrate tape recorder life equivalent to mission life. Although not required for "minimum" redundancy approach, it is recommended.
Attitude Control Subsystem			
Gyros	Even though long life components are used, a redundant gyro is recommended.	$50K	
Wide Band Data Handling			
Config. #1	No redundancy	45.5 watts	No redundancy resulting in slow ground station "handover" with no backup modes.
Config. #2	Switching so either modulator can use either link but no modular backup.	45.5 watts & $15K	A time shared backup is available in the event of a gimbal or TWT failure.
Config. #3 (Recommended)	Switching to allow simultaneous cross link operation.	45.5 watts & $22K	This configuration trades as best compromise between none and total redundancy.
Config. #4	Add 3rd TWT to backup either TWT failure.	60.8 watts & $137K	Backs up TWT failure in either link.
Config. #5	Adds redundant modulators to Configuration #4.	75.9 watts & $222K	Provides a fully redundant system.

It is reasonable to assume the purchase or manufacture of five complete sets of flight hardware to benefit from the cost savings of multiple purchase. The general purpose spacecraft as presently conceived could support the first five missions shown on the model: 5 Band MSS, Seasat A, Solar Maximum, EOS-A and the Seasat B mission. A sixth set of hardware (one of each type) would serve all programs as spares. The number of components involved in this multiple buy are shown in Table 2-12.

Table 2-12. General Purpose Spacecraft Components Required to Support 5 Missions

	QTY PER S/C	TOTAL NO. REQUIRED	SHELF LIFE	REMARKS
ACS MODULE				
Backup Controller	1	6	TBD	
Mag. Compensator	3	16		
Mag. Control	1	6		
Momentum Wheel	3	16		
Electronics, Wheel	1	6		
Star Tracker	1	6		
IRU Platform	1	6		Includes internal redundancy
Solar Aspect Sensors	6	31		
Magnetometer	1	6		
POWER MODULE				
Central Control Unit	1	6		
Power Regulation Unit	3	16		
Power Control Unit	1	6		
Battery	3	16		
S/C Interface Assy	1	6		
Test Connector Assy	1	6		
Solar Array	1	6		
C&DH MODULE				
S-Band Transponder	1	6		Internally redundant
Mod/Demodulator	1	6		Demod internally redundant
Control Command Decoder	1	6		Internally redundant
Format Generator	1	6		
Clock	1	6		Internally redundant
Remote Decoder/Mux	10	51		
S-Band Antenna	1	6		
On-Board Processor (less memory)	1	6		Internally redundant
Memory Modules (S/C)	5	26		
STRUCTURE				
Transition Frame	1	6	>10 years	
Stru. ACS Mod.	1	6	>10 years	
Stru. Power Mod.	1	6	>10 years	
Stru. C&DH Mod.	1	6	>10 years	
Stru. Basic S/C	1	6	>10 years	
THERMAL CONTROL				
Blankets Ins.	1	6	>10 years	
Thermal Coating	1	6	>10 years	
Heaters	1	6	>10 years	
ELECTRICAL DISTRIBUTION				
Wire ACS S/S	1	6	>10 years	
Wire Power S/S	1	6	>10 years	
SCCM	1	6		
Wire Spacecraft	1	6	>10 years	
Wire C&DH S/S	1	6	>10 years	

2.13.2 SHELF LIFE

Shelf life of the hardware as shown in the table indicates that hardware manufactured in 1975 would be considered to be reliable for a 1979 launch and a two-year orbit life, providing that certain storage conditions and exercise of selected components is conducted on a regularly-scheduled basis. Studies conducted on other programs indicate that if the spacecraft is stored in a clean, dry (60% RH or less) non-magnetic and non-UV environment that there should be no storage problems. Some components require special storage techniques such as:

- o Batteries should be enclosed in plastic bags and packed with dessicant bags. After packaging, modules are to be stored at a temperature of 5 ± 5^0 C $(41 \pm 9^0$ F) in a refrigerator or freezer. Periodic testing should be conducted.
- o C&DH components should be stored in an environment in which the magnetic field is less than 50 gauss. Periodic tests should be conducted.
- o ACS gyros must be stored with the spin axis horizontal. Many oils and greases will tend to creep in stationary bearings. Provision should be made for periodic exercise of such bearings.
- o Other aspects of storage that must be considered are such items as cold flow or permanent deformation of rubber, elastomeric or plastic materials under mechanical stress, oxidation or ozonation, and UV light discoloration of coatings. However, with proper procedures and replacement of specific parts, shelf life of hardware can be increased considerably.

In summary, the approach to low cost hardware commonality on the EOS Program consists of the following:

- o Recommendation of multiple buys of hardware with a minimum purchase of sets for at least five spacecraft plus spares.
- o Design of a general purpose spacecraft to use the same hardware to perform multi-mission requirements.
- o Shelf life of 5 years for spacecraft hardware does not appear to be a problem based upon previous studies conducted. It is recommended that certain storage environments be provided, and that selected components be exercised and retrofitted as required.

2.14 INTERNATIONAL DATA ACQUISITION

2.14.1 ALTERNATE METHODS

The value to the U.S. of data gathered outside the boundaries of the U.S. is largely a function of the particular Earth resources mission application under consideration. Global crop inventories or ocean/meteorological missions demand such data and the dollar value associated with gathering global data must ultimately be traded against the predicted value or return expected from such world-wide applications.

The decision is also largely political, i.e., does the U.S. want to provide (and pay for) the capability to supply data to other nations. The precedent has already been set with ERTS and considering the support and investment made by other nations such as Canada, Brazil, Italy, and soon Iran, Venezuela, Japan and others, it is rather clear that international data will continue to be provided for both future operational and R&D Earth resources missions.

The question to be considered then is what is the most cost-effective way to provide this data. Three viable methods exist:

1. Realtime Data Only - no international data acquisition by the U.S. Foreign users get their data via their own ground stations; U.S. provides satellite capability to support multiple international stations.
2. WBVTR - international data acquisition by the U.S. for U.S. users/applications only. Also provides the capability to acquire limited international data where no ground station exists. Foreign users get their data via their own ground stations in realtime.
3. Use TDRSS - essentially the same capability as (2) above, but TDRSS provides nearly unlimited capability to acquire international data.

2.14.2 COST TRADEOFFS

The three alternate methods have several cost impacts in both the spacecraft and ground portions of the EOS system. The significance of the cost trade areas and their impact are identified in Table 2-13. The cost trades clearly show a major increase in total system

Table 2-13. International Data Acquisition Cost Trades

S/S Area	Impact	Effect: R/T Only	Effect: WBVTR	Effect: TDRSS
S/C Structure/ Configuration/ Propulsion	Significant	Lowest cost approach. No special structure or configurations required.	Generally one tape recorder required for each instrument. Reliability could dictate a redundant recorder. Recorders themselves add to S/C weight and require additional structure to support. Weight penalty is ~200 lbs. per recorder to support TM and HRPI instruments. Cost over R/T only case us $380K which is the added cost of the propulsion system for TIIIB. If Delta 3910 is used the added cost is negligible.	Added structure & gimbal assembly for TDRSS antenna. The large antenna limits S/C configuration options. The weight penalty is approx. 65 lbs (not including the antenna or gimbal electronics) for the TDRSS. The cost delta over R/T only case is 375 K (not including the antenna) plus a 380K cost for added propulsion system if a Titan launch is required which is marginal (use of a Delta 3910 would eliminate the additional 380K). The Delta 2910 system assumes an 8-ft antenna while the Titan configuration could use a 10-ft antenna.
Launch Vehicle	Significant	Minimum weight approach, hence no impact on launch system.	Heaviest approach; therefore, maximum impact on launch system. Tape recorders cannot be accommodated in Delta 2910 configuration. Major cost impact since this option demands another launch vehicle. Cost over R/T only case is $6M for Titan or approximately $2.0M for Delta 3910.	Less than WBVTR approach. If an 8-ft TDRS antenna is used the system becomes marginal for a Delta 2910 but acceptable for a Delta 3910. The cost to go to a Delta 3910 is 2.0M. The cost delta for a Titan launch is approx. 6M but this would allow the use of a 10-ft TDRS antenna.
DCS	None	DCS approach not affected by this cost trade.	----	----
HRPI/TM	None	HRPI/TM designs not affected by this cost trade.	----	----
Wideband Communications	Significant	Lowest cost approach. Uses high-gain two-axis driven antenna with all communications in real-time at X-band.	Added cost of WBVTR's is charged to wideband system. Additional switching also required to handle playback as well as real-time data. Cost delta is $1. 5M.	Added cost of TDRSS antenna charged to wideband system. All wideband communication to TDRSS at Ku-band. X-band backup capability recommended. Cost delta over R/T only case is $ 1.5M.
Solar Array	Minor	Minimum power load on spacecraft.	Maximum power load. WBVTR demand 200 watts each while operating. Two recorders slightly increase average S/C power (~ 32 W). Power S/S can accommodate this increase with no design impact.	Increased average power load over that used for R/T only case (8.5 W). Power S/S can accommodate this increase with no design impact.
OBC	Minor	Requires on/off switching only plus wideband antenna drive commands. Algorithm for generating antenna drive commands potentially included in OBC. Costs considered in S/C autonomy section.	Requires on/off switching only plus wideband antenna drive commands. Same antenna drive algorithm as for R/T only case would be used. Costs considered in S/C autonomy section.	Requires on/off switching plus antenna drive commands. Antenna drive algorithm different from previous two cases but roughly the same in complexity. Costs considered in S/C autonomy sections.
LCRS	None	All stations will get data regardless of approach using separate downlink.	----	----
OCC	Significant	Minimum OCC cost case. Standard ERTS-type operation. Direct control of S/C via three primary ground stations. Payload data mailed from remote locations.	Standard ERTS-type operation. Direct control of S/C via three primary ground stations. Payload data mailed from remote locations. Essentially similar to R/T only case but involves additional scheduling of record and playback cycles. Cost to implement EOS control/analysis capability involves less than 20K for software.	Communication to/from S/C via TDRSS control center. Places another control center between OCC and EOS S/C. New interface to be developed. No payload data direct to GSFC in realtime as with the other two cases. All payload data mailed or relayed via wideband satellite link to GSFC for processing. Cost to implement EOS control/analysis capability plus non-recurring cost to develop new interface estimated at $300K.
Ground Stations	Significant	Requires one complete set of wideband receiving site equipment per ground station. Minimum of three sets, potentially four depending on S/C altitude. Since the receiving site equipment is payload unique, recurring cost is a function of S/C payload. ROM for receiving requipment; NR Cost $1,300-K R Cost 500-K Total for 3 sets $ 2.8-M	Same as R/T only case.	One set of wideband equipment at the TDRS receiving sites. Potentially a second set at GSFC if data is relayed via a Domsat from the TDRS site. Goldstone and Alaska not required. Total for 2 sets is $2.3M.
Network Operations	Minor	Standard ERTS-type operation. OCC direct interface with STDN. Standard STDN network support. Network support required at three, possibly four receiving sites.	Same as R/T only case.	Network support required at only the TDRS receiving site under normal operating conditions.
CDP	Significant	Minimum number of scenes returned to CDP facility per day (≈40). Minimum processing load case is lowest cost.	Additional thruput required to support additional data returned per day. Spacecraft recorders plus realtime data provide the capacity to return over 200 scenes per day, although the system will not likely be operated at this capacity. Cost delta over R/T only case is $3.4M. maximum.	Maximum data return capacity provided by TDRS. Scenes per day can easily exceed the WBVTR case but statistically the number of good (cloud free) scenes will be similar to WBVTR case. Cost deltas therefore are roughly the same.
CDP Operations	Significant	Minimum number of scenes per day corresponds to minimum operating cost.	Increase in scenes processed per day increases operating cost in terms of equipment maintenance and people. Cost delta over R/T only case is about $ 3.5M maximum.	Similar to WBVTR case, hence cost deltas over the R/T only case is about $3.5M.
CDP Expendables	Significant	Minimum number of scenes per day corresponds to minimum usage of expendables.	Increase in scenes processed per day increases expendables usage. Cost delta over R/T only case is estimated at $ 2.5M maximum.	Similar to WBVTR case, hence cost deltas over the R/T only case is about $2.5M.

costs to add WBVTR or TDRSS capability. Estimates of recurring costs range from 12.1M to 12.7M for the WBVTR capability vs. 13.6M for the TDRSS capability.

The decision to implement the additional capability to process international data then depends strictly on the relative value of the international data in the performance of resource management tasks.

2.15 FOLLOW-ON INSTRUMENT ACCOMMODATION

The EOS-A spacecraft concept, developed by GSFC and optimized by GE during this study, has the capability to support many other types of Earth orbiting missions. These missions range from sun synchronous, similar to the EOS-A mission, to non sun-synchronous such as Solar Maximum and Seasat, to geo-synchronous typified by SEOS.

The spacecraft consists of a set of general purpose modules, including ACS, Power, C&DH and propulsion, which can be grouped around a structure compatible with Delta, Titan or Shuttle launch vehicles. Together, this grouping is a general purpose spacecraft capable of supporting multiple missions.

The multi-mission capability does not just fall out of the basic EOS-A mission, however; it is the result of careful design and tradeoffs both within the general purpose modules and at the systems level to insure that the EOS-A mission can be satisfied and follow-on missions can be supported at minimum overall program cost.

Many of the subsystem designs are directly driven by EOS-A requirements; i.e., the basic design that satisfies EOS-A will satisfy all other identified missions. In these cases, there is no cost impact to support follow-on missions. In selected areas, the basic spacecraft design is impacted by follow-on instruments or alternate missions. These are summarized in Table 2-14, along with the approach to accommodate each impact and the resulting costs.

Table 2-14. Follow-On Instrument Accommodation

S/S Area	Impact
Mech/Thermal (Subsystem Section Only)	Solar Maximum Mission using EOS-A coatings will result in too low temperatures in the general purpose modules. Requires more costly coating on propulsion module but less costly coating on C&DH, ACS and Power modules. Total cost delta from EOS-A is negligible. Seasat-A has wide Beta angle range and requires change in coatings on ACS and Power modules. Cost increase over EOS-A results. Thermal control cost to accommodate Seasat mission is $4.1K for ACS module and $78K for power module. SEOS, due to its long daylight and darkness periods, has significantly different thermal control problems. Thermal control cost to accommodate this mission is a delta increase of $10K. Coatings must be changed on a per flight basis for these other missions.
ACS	SEOS Mission has low orbital rate requiring additional star sensor to increase the frequency of star updates. Cost increase to perform this mission over EOS-A is $90K. Recommend mission unique modifications to basic EOS-A design to perform this mission. SAR Mission represents maximum load demand on the power subsystem. Additional hardware consisting of two batteries, two power regular units and a larger solar array are required. Batteries and regulators are modular increases to the power S/S and increase its cost by $140K for the SAR mission only. Solar array is mission unique hardware.
C&DH	NONE
OBC S/W	Solar Maximum Mission requires minor modifications to the ACS processing software. Cost to modify is $5K. Recommend this to be a one-time mod for this flight.

Follow-on mission support has been evaluated only where the impact involves the general purpose portion of the spacecraft. Since the instrument portion of the spacecraft is mission unique, and the related equipment is generally not intended to serve multiple missions, its costs were not evaluated.

2.16 SYSTEM REQUIREMENTS ALLOCATION

2.16.1 REQUIREMENTS AND APPROACH

The EOS-A Land Resources Management mission will utilize instruments which sense signature data in the spectral, spatial and temporal distinguishing characteristic subclasses. In order that the utility of this data to the user be maintained at a high level, it is necessary that an overall system design philosophy be utilized which minimizes the discrepancies between the actually sensed distinguishing characteristics and the "approximate" characteristics represented in the EOS output data.

The purpose of the system performance analysis task is to develop an overall system concept to meet the specified system performance requirements which, in turn, insure output data quality. Performance tradeoffs are made between various elements of the total system (e.g., sensors, platforms, ground processing) which allow an "optimum system design" to achieve the desired performance at a minimum cost/risk. The task is broken down into three parts:

1. Specification of a complete and realistic set of baseline system requirements which are consistent with ultimate data utilization.
2. Design of the total system to achieve those system requirements
3. Derivation of subsystem performance allocations which optimize the system configuration in regards to minimizing total cost and risk in achieving the desired system performance.

2.16.2 SYSTEM REQUIREMENTS

In order to make tradeoffs between the various elements of the EOS-A system, it is necessary to first establish which parameters of the system affect the desired distinguishing characteristics of the collected data. The selected system performance parameters and their relationship to data utilization requirements (via the distinguishing characteristics) are illustrated in Table 2-15. These performance parameters provide a continuous thread through the entire EOS system and create a sound basis for optimization of system performance. The impact of these parameters on the various system elements is shown in Table 2-16.

Table 2-15. Impact of System Performance Parameters on Distinghishing Characteristics

System Performance Parameter	Distinguishing Characteristics of Data: Spatial	Spectral	Temporal
Geometric Mapping	o Band-to-Band registration o Sensor-to-Sensor registration o Position Accuracy o Internal Distortion	o Band-to-Band registration o Sensor-to-Sensor registration o Position Accuracy o Internal Distortion	o Internal Distortion o Position Accuracy
Radiometric Mapping	o Band-to-Band radiometric accuracy o Sensor-to-Sensor radiometric accuracy o Radiometric Striping o Absolute accuracy	o Radiometric Striping	o Radiometric Striping o Radiometric Stability
Dynamic Response	o Radiance estimation o Boundary location o Threshold size o Threshold radiance	o Boundary location o Threshold size o Resolution	o Radiance estimation o Boundary location o Threshold size o Threshold radiance

These performance parameters have been grouped into three categories: geometric mapping, radiometric mapping, and dynamic response. Geometric and radiometric mapping parameters are the standard large area, low frequency error sources which have been considered in previous earth resource data collection systems (e.g., ERTS). However, since the baseline system performance requirements are considerably more stringent for EOS than for previous systems, additional dynamic, or high frequency, error sources must be considered to evaluate system performance and specify subsystem performance allocation budgets.

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Geometric Mapping Accuracy. The key requirement of an automatic multidimensional analysis system using EOS data is the availability of a set of congruent measurements for each resolution element in the output data (e.g., Band-to-Band per sensor as well as TM visible to TM Thermal to HRPI visible). Multiple measurements from each image resolution element on the ground offer a means of improving the recognition accuracy of scene properties. Measurements of reflectance and radiance from microwave, thermal and reflective infrared, through the visible wavelengths and into the ultraviolet region derived from non-EOS sources can also be utilized for analysis of each image point if congruence of these measurements can be achieved.

The necessity for geometric correction is generated primarily due to uncertainty in platform position and motion (ephemeris, attitude and attitude rates, structural deformations), sensor induced distortions (aberrations, boresighting, scan non-linearities), and geometry of the imaging process (earth rotation and curvature, terrain elevation, viewing perspective).

The baseline geometric mapping specifications for EOS-A digital data consider low frequency, non-scene dependent errors, that would occur in a noise-free system. These have been expanded to include requirements for along track internal distortion, sensor-to-sensor registration, and geometric mapping accuracy requirements for local user station data.

Radiometric Mapping Accuracy. Accurate radiometry is needed to allow identification and classification of materials on the surface of the earth based on their spectral reflectance characteristics. Radiance incident on the input aperture of the EOS sensors is not directly proportional to the reflectance of the material in the IFOV due to the effects of the viewing and illumination geometry (seasonal changes, illumination angle, terrain relief) and the atmosphere (scattering attenuation, view angle, path luminance). In addition, the collection system (e.g., instruments, digitizer) further degrades the fidelity of the received radiance. Therefore, a radiometric correction function must necessarily be performed if the quantum level associated with an IFOV area on the ground is to be proportional to its actual spectral reflectance.

The baseline radiometric mapping specification for all processing facilities (central data processing as well as local user stations) has been developed and expanded in several areas in an attempt to improve the utility of the data for the user. For example, the banding accuracy requirement is specified as a function of received radiance. This is to minimize the impact of banding on degradation of material radiance histograms at the low end of the radiance scale.

Dynamic Response. Because the geometric and radiometric mapping accuracy requirements are very stringent for the EOS-A mission the dynamic performance of the system must be considered in determining over-all quality of the output data. Whereas, geometric and radiometric accuracies are based on the input to output mapping of slowly varying radiometric and geometric errors, the errors introduced due to the dynamic performance "requirements" have not been specified but rather used as a guide in determining data utility, optimizing system design (sensor, C&DH) and determining the validity of the geometric and radiometric mapping accuracy requirements. The four dynamic performance descriptors which have been used are shown in Table 2-17.

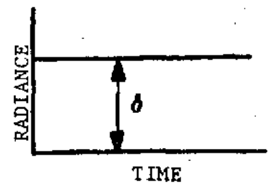
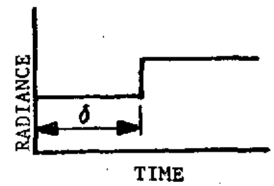
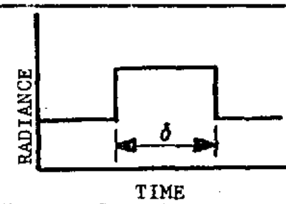
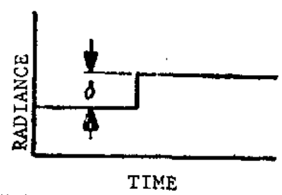
2.16.3 COST/PERFORMANCE TRADE-OFFS

The initial performance analysis and error budgets used reasonable judgement as to what was achievable in each subsystem area. As the various subsystem areas evaluated the impact of achieving their requirements all of the cost data and risk factors were reviewed and reallocations made if necessary. However, four system tradeoff areas involved major costs/risks which were not resolved by cost/performance reallocations among the subsystems. These areas are:

- Positional accuracy with GCP's
- Wideband data rate
- Ephemeris accuracy
- ACS performance vs. ground control

The costs/risk impact is described briefly along with "at this point in time" conclusions regarding their disposition.

Table 2-17. Dynamic Performance Descriptors

Dynamic Performance Parameter	Description	Example
Radiance Estimation Error	o The error in determining the value of the radiance of an area above threshold size. o Directly proportional to system noise PSD o Inversely proportional to bits/sample.	
Boundary Location Estimation Error	o The error in determining the location of a step change between constant radiance areas. o Directly proportional to system noise PSD o Inversely proportional to system MTF, samples/IFOV and bits/sample.	
Threshold Size	o The smallest dimension object for which the functions defined above hold (e.g., the resolution cell size). o Inversely proportional to the system MTF and samples/IFOV.	
Threshold Radiance	o The smallest radiance change which can be detected o Directly proportional to system MTF, noise PSD and samples/IFOV o Inversely proportional to bits/sample	

Positional Accuracy with GCP's. The requirement in the NASA Specification for positional accuracy utilizing ground control was $\pm$ 15 meters. This is interpreted as the RMS of the residual errors resulting from location measurements for a large number of points in the data with respect to a given reference (e.g., UTM projection, etc.). There are many sources of error which degrade the position accuracy of the data as shown in Table 2-18.

The limitations imposed on remaining errors due to many of these sources is strictly a function of how accurately the ground processing system calculates and implements the correction function. Examples of this type of error source are earth curvature, earth rotation and projection. The inaccuracies due to other sources is a function of how accurately pre-launch calibration and testing measurements are performed such as optical distortion effects, detector location uncertainties, and alignment offsets. The effects of the remainder of the error sources must be removed by information derived from ground control point location data. The subsystem performance allocations have been formatted to achieve this with a minimum system cost impact.

Table 2-18. Sources of Geometric Position Mapping Error

Mapping Error Sources	Dynamic Error Sources
Sensor	Noise
Scan Stability	
Optical Distortion	Sampling
Detector Configuration	
Platform	MTF
A/C Subsystem	
Structural Stability	Quantization
Clock	
Ephemeris	
Digitizer	
Timing	
External	
Projection	
Curved Earth	
Earth Rotation	
Terrain Relief	
Ground System	
Computational Accuracy	
Modeling Technique	
GCP Location Error	

However, there are some error sources for which ground control data is not sufficient and, therefore, must be removed in some other manner. For example, terrain relief represents a random error whose error effect varies with position in the field of view of the instrument and can only be removed using a terrain relief model. The errors due to the dynamic response of the system (noise, sampling, quantization, spread function) are completely random and can never be removed.

Table 2-19 categorizes the various sources of errors that contribute to the resulting RMS measured positional accuracy and shows the anticipated contribution of each.

Table 2-19. Major Contributors to Total System Positional Error

	Range	Normal
GCP Location Error	6-10m	8m
Correlation Error	8-15m	12m
Terrain Relief	5-15m	10m
Ground System Error Correction	8-12m	10m
Dynamic Response (ΔR=10%)	10-20m	15m
Measurement	10-15m	13m
Total RMS (1σ)	20-37m	29m

Two points are made by this table. First, overall mapping accuracy of the system will not be better than about one pixel. Second, improving (decreasing) the ground system error correction allocation will increase ground system cost without making any measurable improvement in total system mapping accuracy.

Wideband Data Rate. The information data rate has a large cost impact on several elements of the system such as the instruments, MOMS, the wideband communication modules, and the ground system. The effect of sampling and digitizing the analog signal out of the instruments was examined in order to define the optimal information data rate to allow a performance/cost trade between the configuration of these subsystems. The system dynamic performance parameters were used as the masure of overall data quality.

It was necessary to determine the allocation of bits/sample and samples/IFOV which optimizes performance as a function of total bit rate. For each practical combination of quantization level and number of samples/IFOV, the respective ratios of digital record error to analog signal error were multiplied to yield a combined "penalty factor" for that particular sampling strategy. Penalty factor was plotted vs. number of samples/IFOV to yield a family of curves, each curve corresponding to a particular number of quantization bits for each candidate sensor and band. Moreover, since a given number of samples/IFOV and number of bits/sample corresponds to a given total bit rate, curves of constant bit rate were drawn on the same axes. The optimum sampling strategy for a given bit rate is the point which minimizes the penalty factor within the bounds of that particular total bit rate curve.

An example of the results of the edge estimation analyses is shown in Figure 2-2 for Band 1 of the Hughes Thematic Mapper. This shows that a higher information data rate does indeed improve performance. For example, if 200 mbps were available, an over-sampling of 1.55:1 and a quantization of 10 bits would optimize the system performance with a penalty of about 1% compared to 2:1 over-sampling and infinite quantization. However, for this particular case the improvement in performance over this optimum for a 100 mbps band limitation (9 bits and 1.16:1 over-sampling) is only about 4%. The penalty due to 1:1 sampling and that quantization is about 18% poorer performance in edge estimation for this particular case. 18% corresponds to approximately 3 meters in resolution performance.

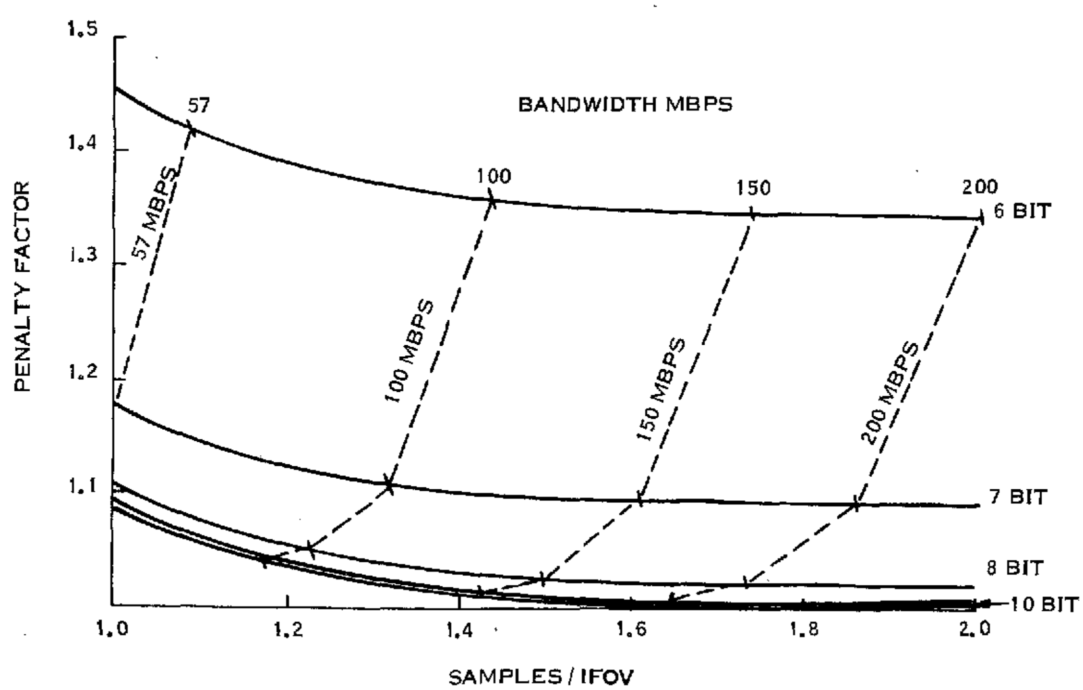


Figure 2-2. Examples of Edge Estimation Analysis Results

As a result of this type of analysis for all spectral bands, the recommended sampling/IFOV for both TM and HRPI is 1:1 and the recommended quantization level is 7 bits for both instruments.

Ephemeris Accuracy. A major uncertainty in determining the allocation of errors to subsystems was the characteristics of ephemeris position and velocity errors for EOS. This impacts the number of ground control points necessary to correct for high frequency ephemeris errors and reduces the requirements on other subsystems. Two bounds were assumed on ephemeris knowledge error as shown in Figure 2-3. The most stringent ephemeris requirement corresponds to the case where two ground control points, one at either end of the swath, are sufficient to correct for ephemeris. The corresponding ephemeris velocity error is 0.01 meter/second over a 20 minute period. The least stringent requirement corresponds to the case where 10 ground control points are spaced approximately equal intervals over a 20 minute swath. This corresponds to velocity error of about 0.05 meters/second.

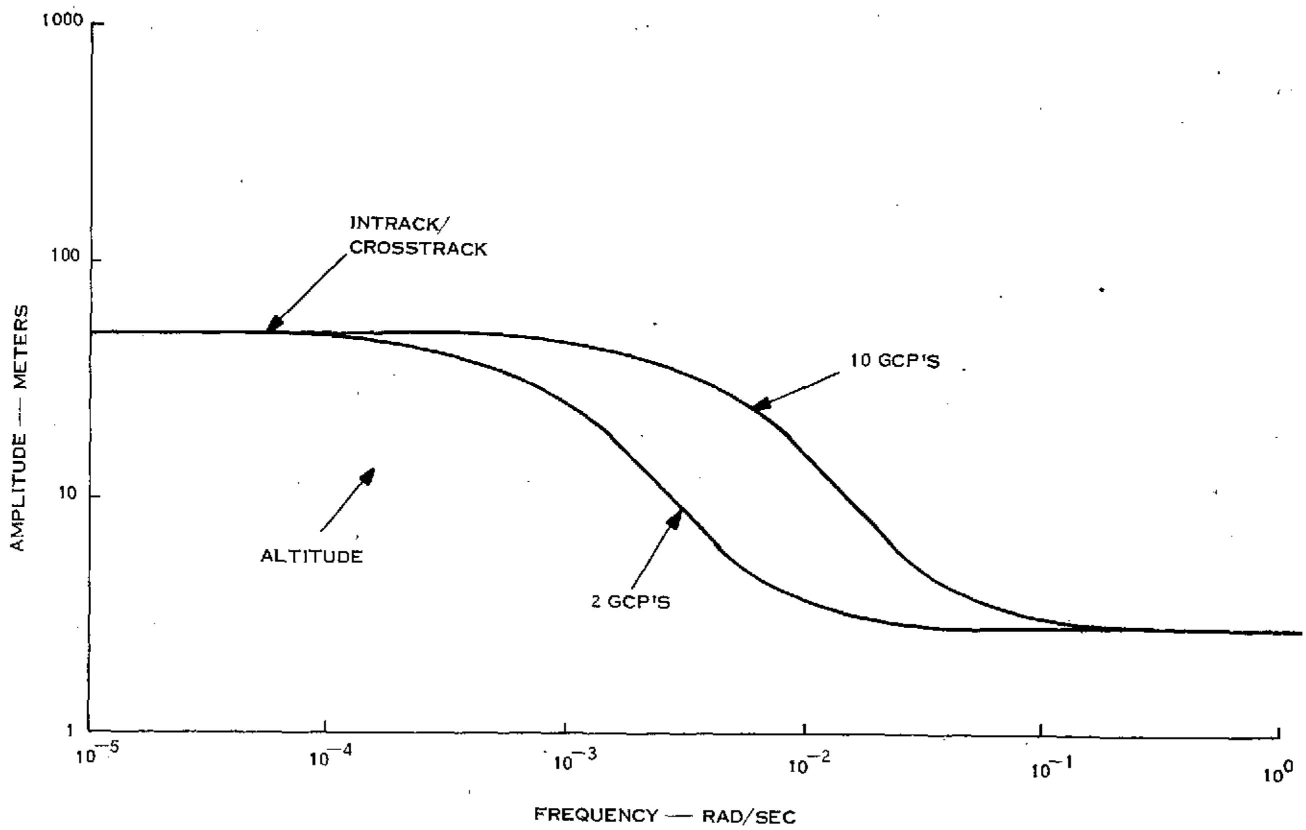


Figure 2-3. Best Fit Ephemeris Accuracy Requirements

Currently, estimates of the accuracy of the ephemeris data are unavailable. It is possible that when they are, they may fall outside the bounds discussed above. This could cause a major change in the data processing concepts being used.

Attitude Control Subsystem. The spacecraft attitude pitch, roll and yaw measurement accuracy requirements (knowledge with respect to inertial reference) are shown in amplitude vs. frequency plots in Figure 2-4. For pitch and roll the position requirements (0.008°) are independent of the number of GCP's since it is determined by the $\pm$ 170 meter accuracy requirement without ground control. The low frequency yaw attitude requirement is more stringent than pitch and roll because it is determined by the along track linearity specification. This system requirement is based on the necessity to reduce initial distortions in data not resampled in y. The high frequency magnitudes are sufficiently small to not require correction and are therefore also independent of the number of GCP's. The middle frequency components of the pitch and roll rate error (10^{-1} to 10^{-4} rad/sec) are those that must be modeled using GCP information and are therefore dependent on their number. The allowable error bounds are shown for both 2 and 10 GCP's per 20 minute swath.

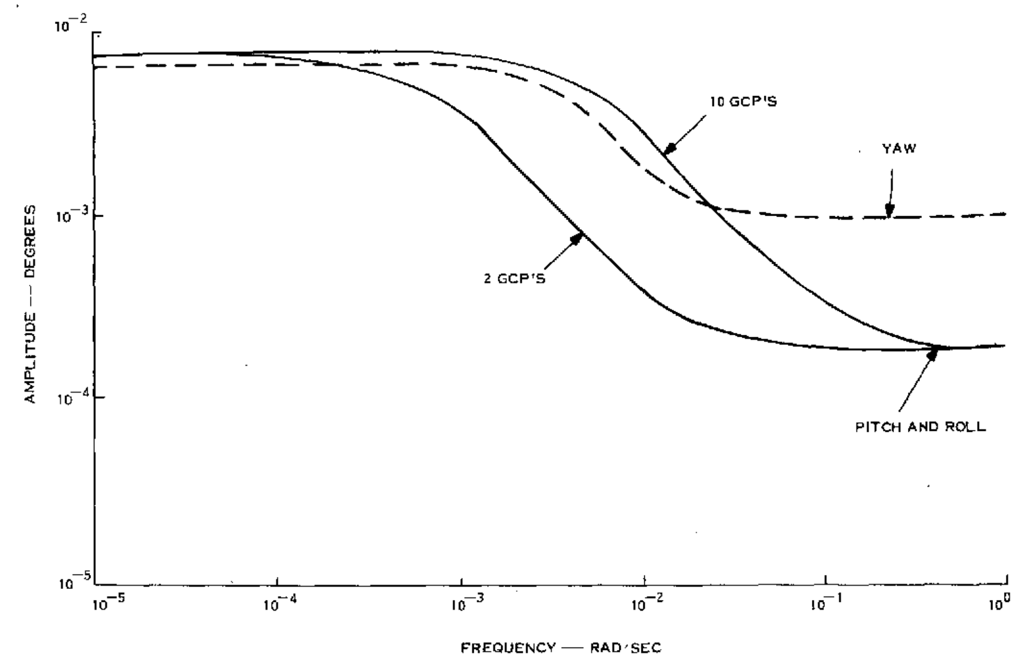


Figure 2-4. Spacecraft ACS Measurement Requirements

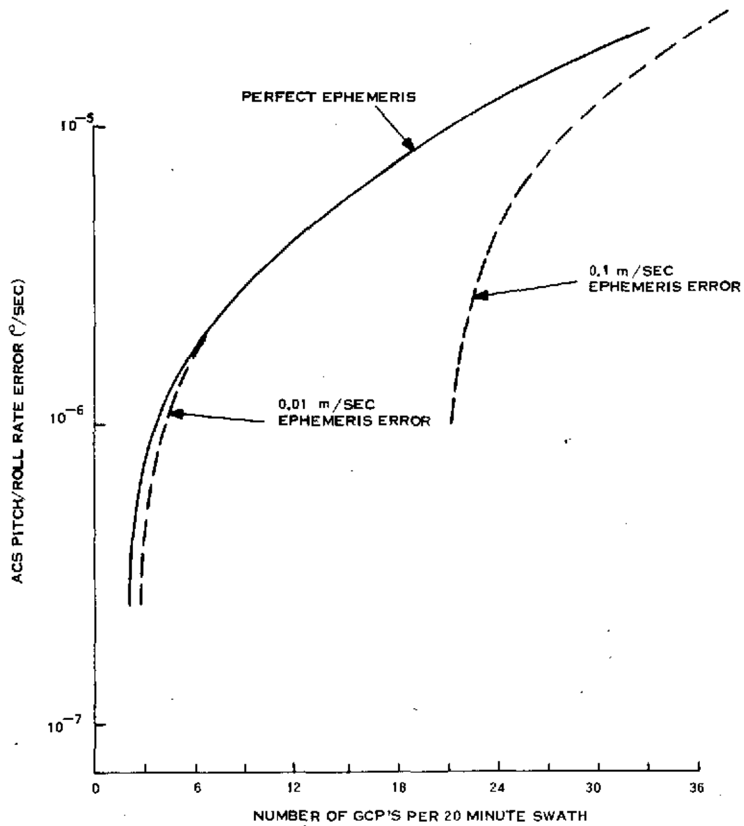


Figure 2-5. Effect of Attitude and Ephemeris Errors on Number of GCP's

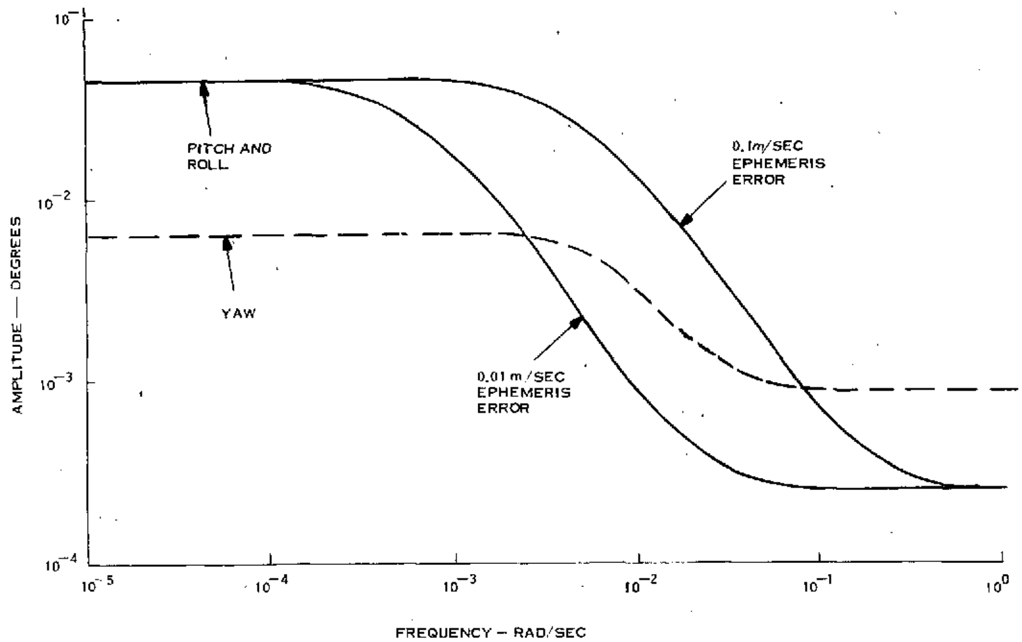


Figure 2-6. ACS Nadir Pointing Requirements

The impact of ephemeris on the number of GCP's and the relationship to ACS performance is shown in Figure 2-5. The spacecraft attitude pitch, roll and yaw control accuracy requirements (control with respect to spacecraft nadir line) are shown in Figure 2-6. Again, the more stringent yaw requirements are due to the along track linearity requirement for unresampled data. The major contributor to the low frequency position error is the ephemeris position error.

The cost delta to achieve the positional accuracy with ground control is shown in Figure 2-7 as a function of the ACS rate accuracy under the following assumptions:

Cost per GCP - $100

- Storage
- Definition
- Computation

Number of areas required to be archived per GCP	X4
Number of Swaths	25

2.17 SPACECRAFT VERSUS GROUND FUNCTIONS

There are several image processing functions which can be performed on-board the spacecraft by using the OBC and software to control the instruments (e.g., scan rate and profile), the wideband data handling module (e.g., sampling rate), and the attitude control module (rate profile control). The implementation of these functions in the spacecraft eliminates the need to duplicate the hardware, software, and operations necessary to complete them on the ground at both a central data processing facility and at many low cost readout stations. Therefore, these functions provide the basis for an on-board vs. ground image processing cost tradeoff.

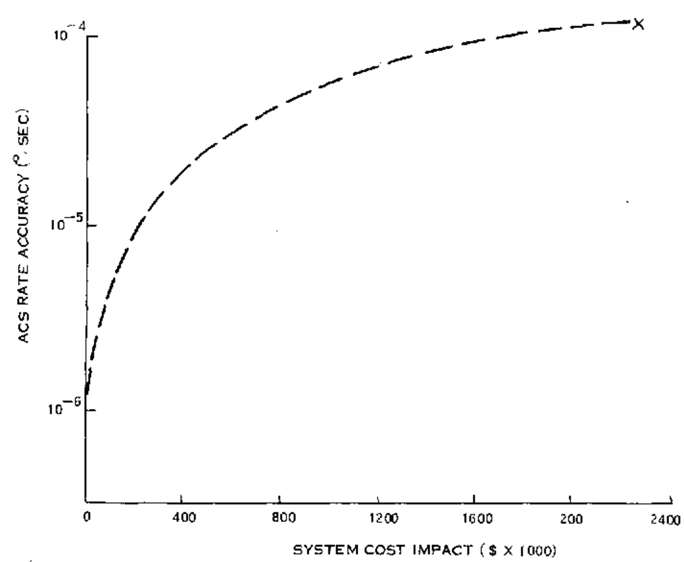


Figure 2-7. Cost Impact of ACS Rate Accuracy

Table 2-20 contains a listing of these processing functions along with a brief description of the impact of the various spacecraft subsystems and ground processing facilities involved in the cost trades. Techniques were synthesized and costed for performing these functions in the low cost readout station, the central data processing facility, and on-board the spacecraft. These costs, both recurring and non-recurring, are shown in Table 2-21, with differentiation made for the line scanning (both Thematic Mapper and scanning HRPI) and linear array types of instruments. Spacecraft costs were determined for the cases of: (1) correcting all the data from the instrument; or (2) only correcting the compacted data sent to the LCRS. These costs represent total effort required to perform that function including system requirements definition and analysis, algorithm and software development, subsystem interface hardware, and potential processor impact data. There are several independent parameters which effect the cost trade results, the major ones being:

- o Function type
- o Instrument type
- o Number of low cost readout stations
- o Number of central data processing facilities
- o Number of missions

The trades were performed individually for each function and instrument type assuming there will be one CDP facility and leaving the number of LCR stations and missions as variables.

Figures 2-8 thru 2-14 depict the total system costs (both spacecraft and ground) to correct the data as a function of the number of missions and LCR stations for the following cases:

- o All processing performed on the ground so that the total system cost is heavily dependent on the number of LCR stations.
- o Only data sent to the LCRS is corrected on the spacecraft. Therefore, the cost of correction in the CDP facility is a factor but since only one was assumed as baseline, the costs are independent of the number of LCRS
- o All data is corrected on the spacecraft making the system costs dependent only on the number of missions.

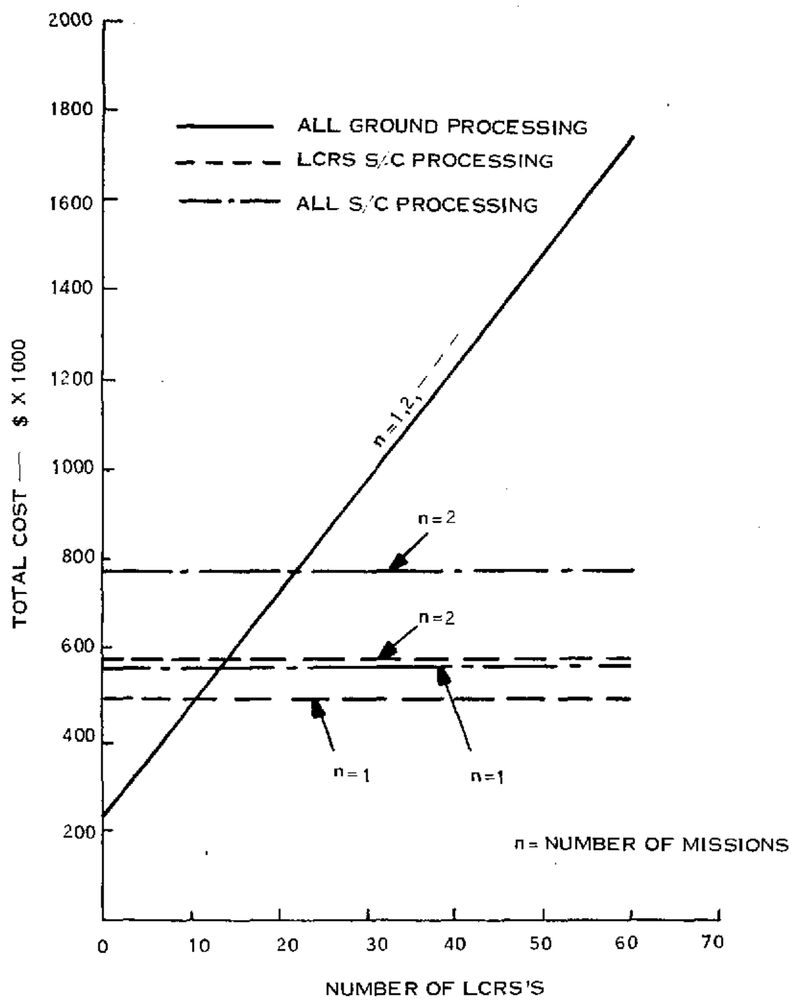


Figure 2-8. Total System Cost to Achieve Linearity of Line Scanner Data

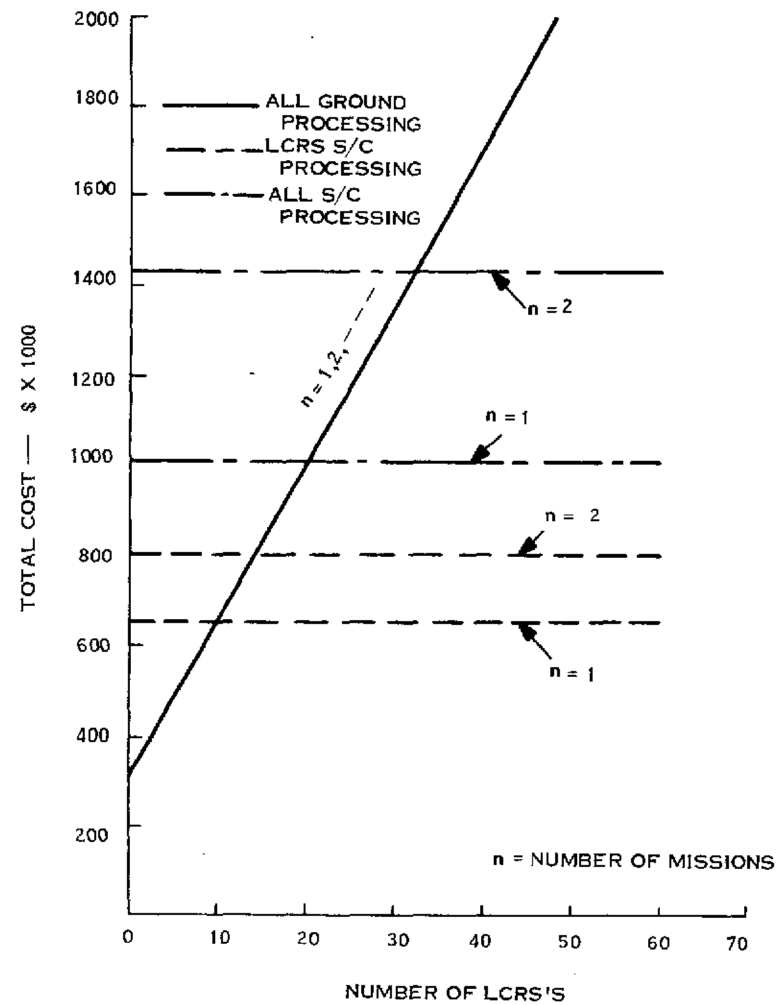


Figure 2-9. Total System Cost to Achieve Linearity of Array Data

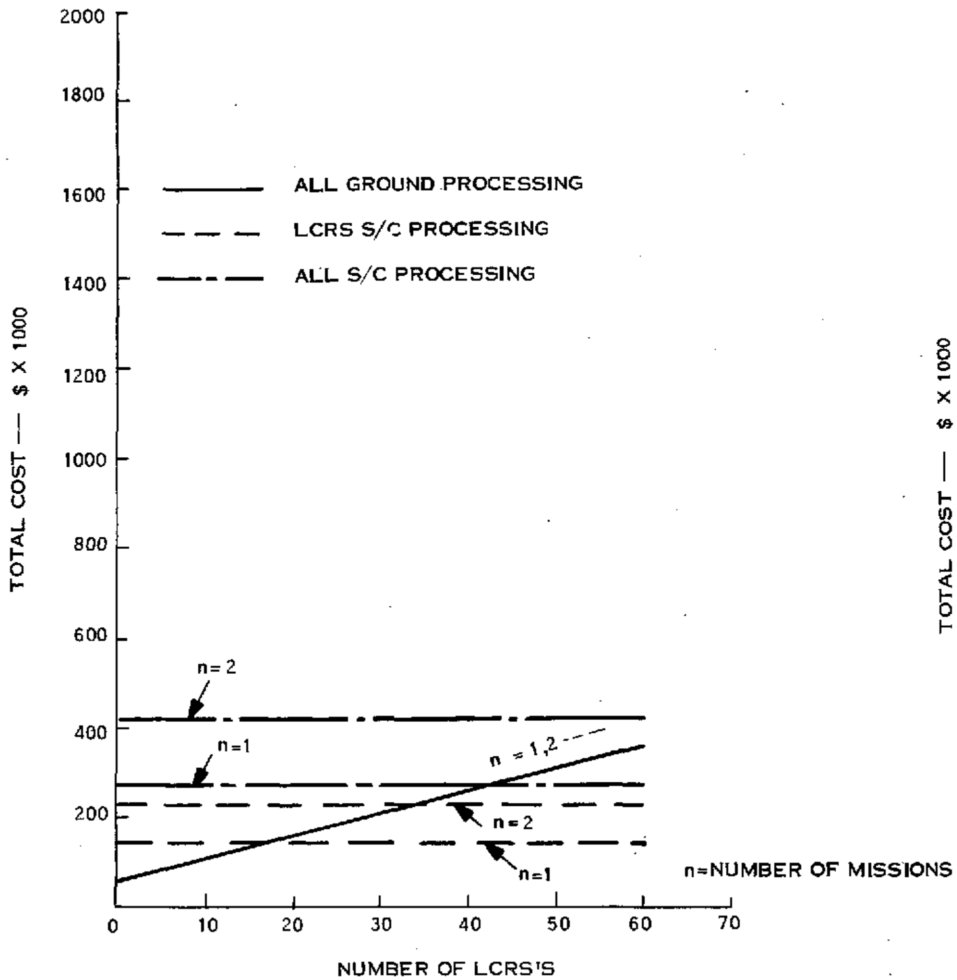


Figure 2-10. Total System Cost to Achieve Band-To-Band Registration of Line Scanner

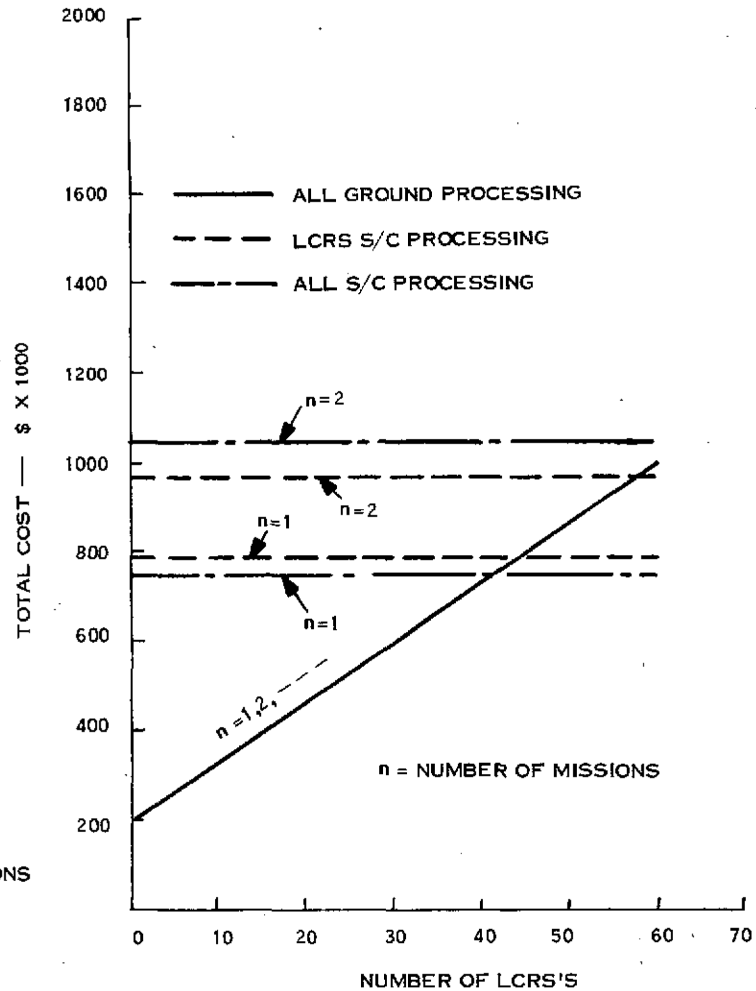


Figure 2-11. Total System Cost To Achieve Radiometric Correction of Line Scanner Data

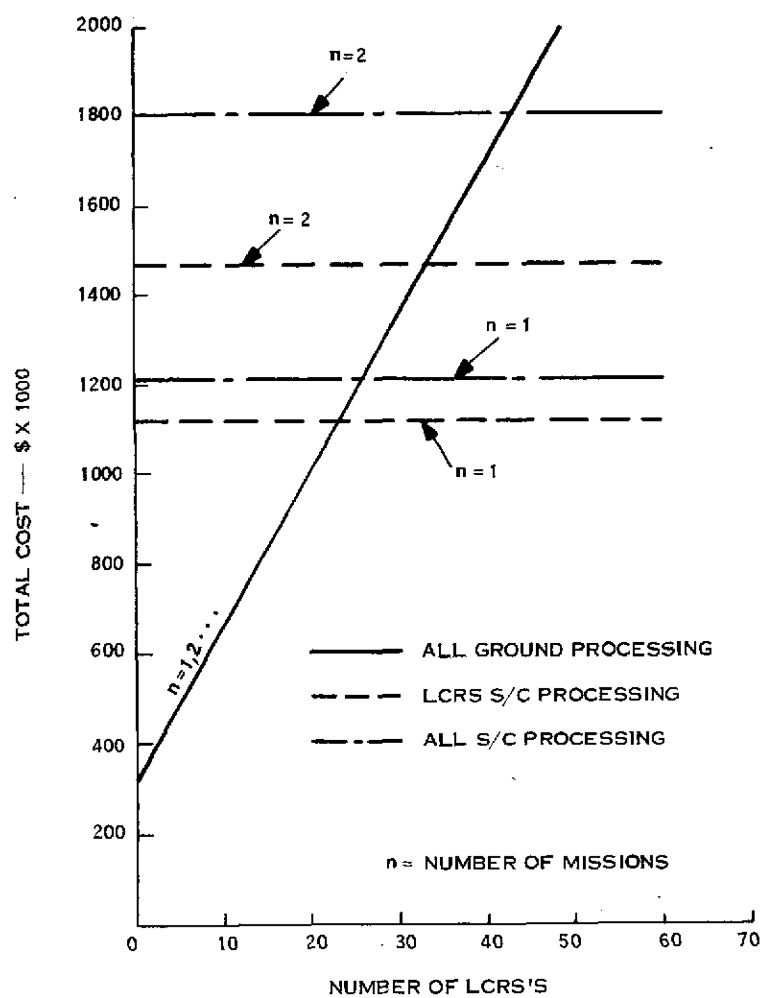


Figure 2-12. Total System Cost to Achieve Radiometric Correction of Linear Array Data

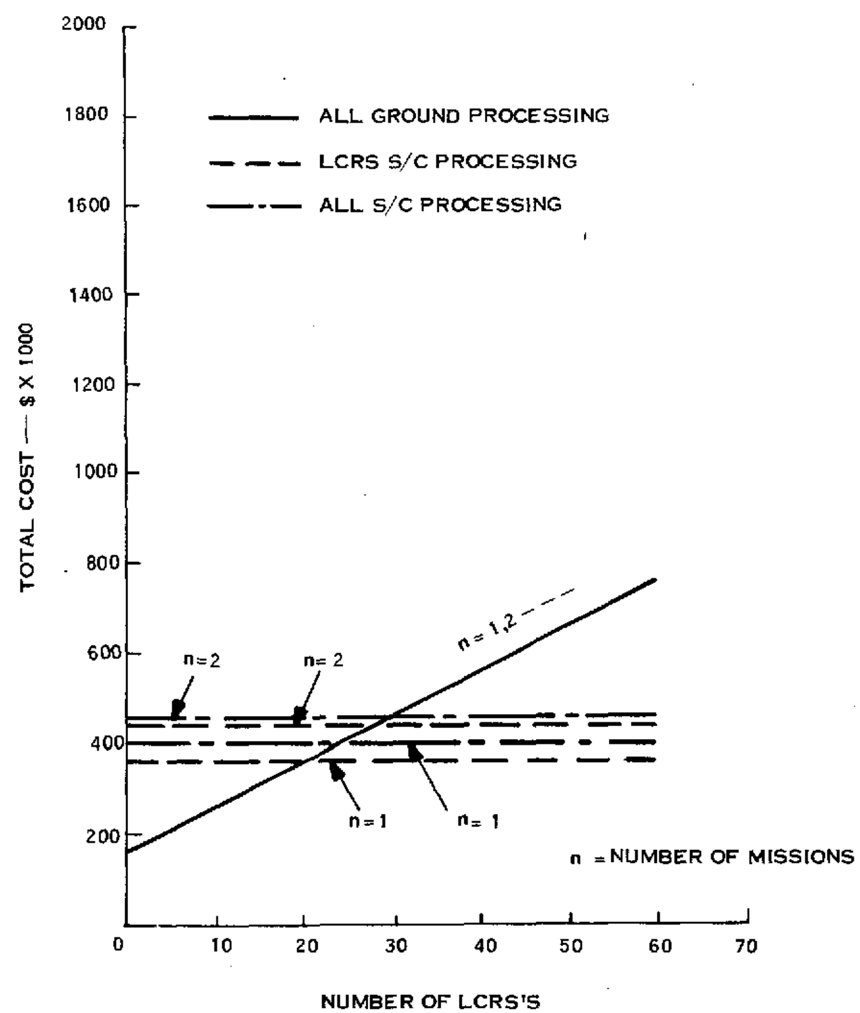


Figure 2-13. Total System Cost to Annotate Line Scanner or Linear Array Data

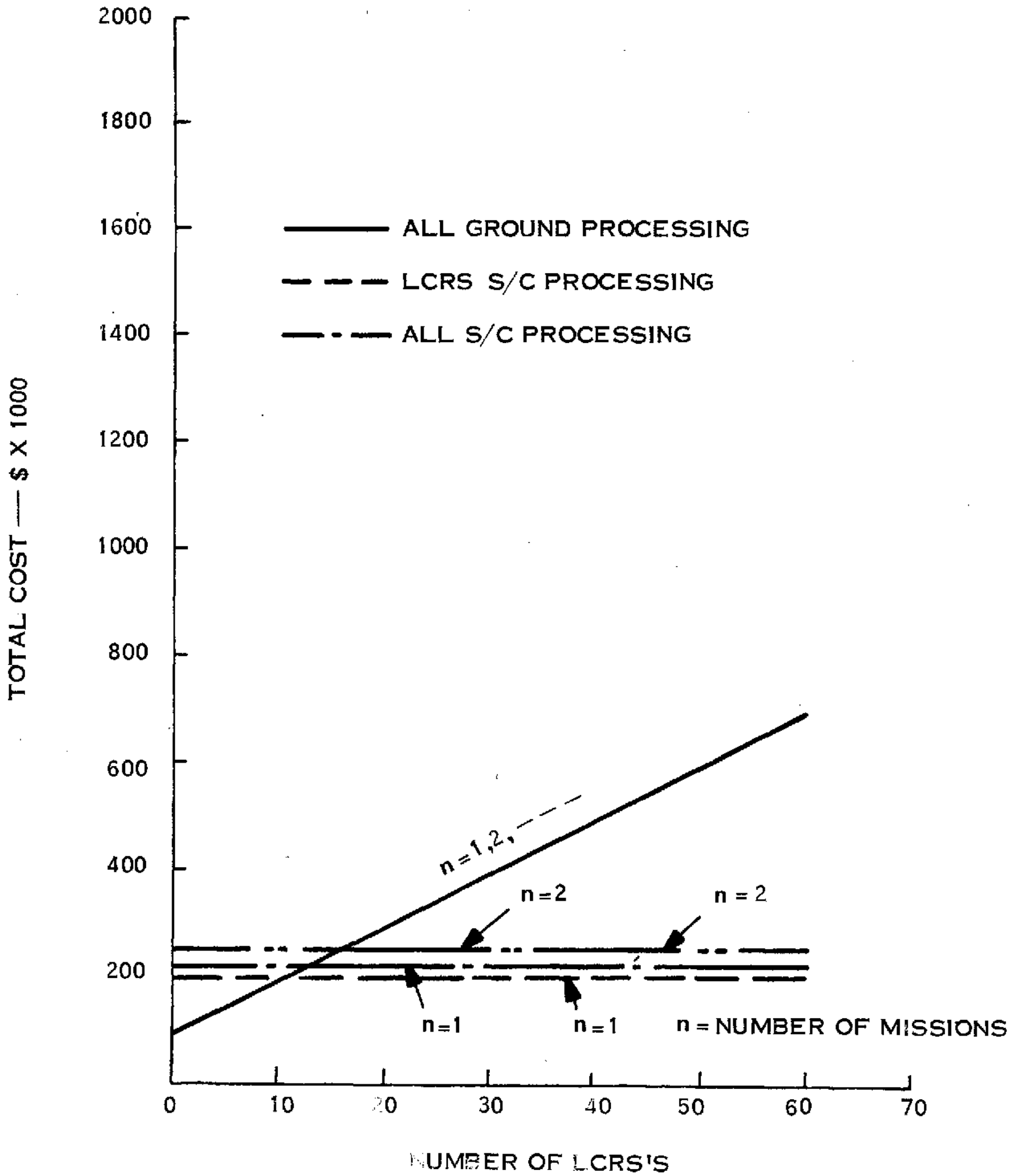


Figure 2-14. Total System Cost to Insert Auxillary Correction Data in Line Scanner and Linear Array Video

Table 2-20. Impact of Data Processing Functions on Various System Elements

FUNCTION	LINE SCANNERS	LINEAR ARRAY	W B D H	ON-BOARD SOFTWARE	W/B COMMUNICA.	A C S	VEHICLE STRUCTURE	C D P	L U S
Cross Track Linearity	Cost to achieve scan profile non-linearization to account for all across track errors - Not practical due to magnitude of cost impact	- - - -	Cost to implement sampling rate variation over one sweep time.	Cost to compute variable sampling on instrument scan rate - Storage cost to maintain current correction	Cost to compensate or accept variable data rate	No Impact	No Impact	Cost to perform an X correction (across track) - Hardware - Software Performance impact on not resampling uncorrected data	Cost to perform an X correction at each LCRS - Hardware - Software Performance impact on not resampling uncorrected data
	- - - -	Design of array detector spacing or sampling to account for non-linearities across track - Not practical for off axis pointing - impractical for cost reasons	Cost to resample and linearize data	Cost to compute visble sampling profile.	No Impact	No Impact	No Impact	Cost to perform an X correction (across track) - Hardware - Software Performance impact on not resampling uncorrected data	Cost to perform an X correction (across track) - Hardware - Software Performance impact on not resampling uncorrected data
Along Track Linearity	Cost to minimize cross scan jitter Cost to vary long term mirror scan rate	- - - -	Cost to implement variable sampling rate over long term	Cost to compute variable sampling rate on ACS profile	Cost to compensate for or accept variable data rate	Cost to implement pitch and yaw rate and position profile	Cost to meet stringent stability requirements	Cost to compute & implement Y correction w/o GCPs Performance impact of two dimensional resampling	Cost to compute and implement Y correction at each LCRS Performance impact of two dimensional resampling
	- - - -	Cost to insure integral of pixel spacing along track - Not practical due to offset pointing Cost to vary sampling rate.	Cost to implement variable sampling rate over long term Cost to implement sampling sequence to insure integrated pixel spacing.	Cost to compute sampling rate variation	Cost to compensate for or accept variable data rate	Cost to implement pitch & yaw rate and position profile	Cost to meet stringent stability requirements	Cost to computer & implement Y correction w/o GCP's Performance impact of two dimensional resampling	Cost to compute & implement Y correction w/o GCP's Performance impact of two dimensional resampling
Band-to-Band Registration	Sensor design cost to insure integral band-to-band offsets Cost of instrument design to minimize pixel offsets	- - - -	Sampling strategy to insure integral pixel offsets Cost of buffering to register data in serial data	No Impact	No Impact	No Impact	No Impact	Cost to implement band-to-band registration reformatting	Cost to implement band-to-band registration reformatting at each LUS
		Cost of instrument optical design and array implementation to band-insure band-to-band registration	Sampling & multiplexing strategy to insure band-to-band registration in data stream Cost of buffering to accomplish registration	No Impact	No Impact	No Impact	No Impact	Cost to implement band-to-band registration reformatting	Cost to implement band-to-band registration reformatting at each LCRS
Data Annotation (to 450 meter accuracy using predicted ephemeris)	No Impact	No Impact	Cost to input annotation in data	Cost to compute annotation position	No Impact	No Impact	No Impact	Cost to compute & insert annotation in data	Cost to compute and insert annotation data at each LCRS
Radiometric Correction (Banding and Long Term Stability)	Cost to provide calibration lamp for cal data	- - - -	Cost to implement a radiometric correction - Table lookup	Cost to compute radiometric correction coefficients	No Impact	No Impact	No Impact	Cost to compute and implement radiometric correction	Cost to compute and implement radiometric correction
	- - - -	Cost to derive calibration data from internal lamp	Cost to implement a radiometric correction - Table lookup	Cost to computer radiometric correction coefficients	No Impact	No Impact	No Impact	Cost to compute and implement radiometric correction	Cost to compute and implement radiometric correction
Correction Data Added to Video Stream	- - - -	Cost to insert correction data on video	Cost to store and/or compute correction data	Cost of increased command handling	No Impact	No Impact	No Impact	Cost to correct data with ancillary correction information	Cost to send auxillary data to LCRSvs, cost to model all errors in correction

Table 2-21. On-Board and Ground Image Processing Costs

FUNCTION	INSTRUMENT TYPE	ON-BOARD PROCESSING COSTS: ALL DATA	ON-BOARD PROCESSING COSTS: LCRS DATA, ONLY	GROUND PROCESSING COST: L C R S	GROUND PROCESSING COST: C D P	REMARKS
LINEARITY	Line Scanner	MOMS: NR 300K R 200K OBC: NR 50K R 10K	MOMS: NR 210K R 80K OBC: NR 40K R 5K	NR 75K R 25K	NR 75K R 80K	• Assumes conical scan corrected only along nominal scan arc. • Only an X correction is required • Correction applied by variable sampling rate for all data case • TM and Scanning HRPI use same circuitry in WBDH module.
	Linear Array	MOMS: NR 500K R 400K OBC: NR 80K R 25K	MOMS: NR 290K R 140K OBC: NR 80K R 10K	NR 110K R 35K	NR 100K R 100K	• Both an X and Y correction to achieve linearity requirement.
BAND-TO-BAND REGISTRATION	Line Scanner	MOMS: NR 120K R 150K	MOMS: NR 70K R 20K	NR 10K R 5K	NR 30K R 20K	• Instrument baseline designs provide integral pixel offsets in TM and scanning HRPI . • Conical scan increases cost in LCRS and CDP by 100% & on-board by 30%. • Linear array is band-to-band registered
ADIOMETRIC CORRECTION	Line Scanner	MOMS: NR 390K R 250K OBC: NR 70K R 45K	MOMS: NR 310K R 150K OBC: NR 70K R 35K	NR 60K R 15K	NR 90K R 50K	• Not valid for CCD HRPI approach. • Assumes two point calibration data supplied by internal lamp
	Linear Array	MOMS: NR 500K R 550K OBC: NR 110K R 50K	MOMS: NR 450K R 300K OBC: NR 100K R 45K	NR 100K R 35K	NR 120K R 100K	•Not practical for on-board function due to significant weight & power impact.
ANNOTATION OF DATA	Line Scanner and Linear Array	MOMS: NR 180K R 50K OBC: NR 100K R 50K	MOMS: NR 150K R 35K OBC: NR 80K R 25K	NR 50K R 10K	NR 80K R 25K	•Assumes scanner and array data are formatted similarly in WBDH module.
ANCILLARY CORRECTION DATA INSERTION	Line Scanner and Linear Array	MOMS: NR 120K R 30K OBC: NR 30K R 20K	MOMS: NR 100K R 20K OBC: NR 20K R 10K	NR 20K R 10K	NR 50K R 20K	• Data handling in the CDP is the major cost factor. • Timeliness is the major performance factor.

To illustrate the use of these curves, consider the plots of total system cost to achieve linearity of line scanner data shown in Figure 2-8. The cost to correct only the data sent to the LCR station is always less than correcting all the data, regardless of the number of missions. However, the cost of correction on the ground is less than the all data or the LCRS cases for the number of LCRS's less than 14 and 11, respectively. The recommendation to achieve minimum cost is to resample (in X, only) the data before it is sent to the LCR station. If all the data is corrected in X, the approach utilized is to vary the sampling rate to compensate for along scan non-linearities so resampling is not required in X and its utility is enhanced because of reduced radiometric error. This is not the minimum cost approach, however, and must be evaluated on its enhancement in performance.

The recommendations below are made as a result of the on-board vs. ground cost trades study. Table 2-22 contains total system costs utilizing the recommended processing approach for one through three missions as well as the costs to perform all functions on the ground. Under the assumption that 20 LCR stations will be added per mission, the total system cost saving is 0.8, 2.0 and 3.1 million for one through three missions, respectively.

1. <u>Linearity</u>

   Implement on-board resampler for line scanner data to perform X correction of all data sent to LCR station.

   Implement on-board X, Y correction to linearize pushbroom array data sent to LCRS only.

2. <u>Band-to-Band Registration</u>

   Implement for LCRS data only

3. <u>Radiometric Correction</u>

   Perform all radiometric correction on ground for linear array and scanner data.

4. <u>Annotation</u>

   Annotate LCRS data only on-board the spacecraft

5. <u>Auxiliary Data</u>

   Send auxiliary data to both the LCRS and CDP facilities.

Table 2-22. Comparison of Total Costs for All Ground Processing and Recommended Approach

Number of Missions	1	2	3
Number of LCRS	20	40	60
All Ground Processing Cost	4.1 M	6.7 M	9.3 M
Recommended Approach Cost	3.3 M	4.7 M	6.2 M
Cost Savings	0.8 M	2.0 M	3.1 M

2.18 SPACECRAFT VS. SHUTTLE FUNCTION

The Orbiter is currently being designed to offer support services to payloads in a number of areas including: (a) delivery to and retrieval from orbit; (b) structural/mechanical; (c) electrical power; (d) communications; (e) data handling; (f) thermal control; (g) guidance, control and navigation. The capabilities of the Orbiter in each of these areas and the support available to EOS are detailed in JSC #07700, Volume XIV, Space Shuttle System Payload Accommodations. The cost impact in each of these areas is described in Table 2-23.

2.19 COST VS. WEIGHT AND VOLUME TRADES

Previous spacecraft design practice has been to emphasize optimizations on a weight performance basis. More important for EOS will be the trades involving cost vs. weight or volume while maintaining performance. The objective of this section is to cost trade the use of larger and heavier components at a low cost vs. smaller and lighter components at a higher cost.

The first step in this study was to establish a cost per pound criteria. This is summarized in Section 2.19.1 and is $2-K/pound. The following sections summarize the significant cost/weight tradeoffs using this criteria where appropriate.

Table 2-23. Spacecraft vs. Shuttle Function Cost Trades

FUNCTION	COST/IMPACT	DESCRIPTION
Structural/Mechanical	Negligible to 250K	Structural and mechanical interfaces between the EOS and Shuttle Orbiter are assigned to the Flight Support System (FSS). Definition of this hardware is the responsibility of RI. Specific hardware trade studies are dealt with in Section 3.1. FSS functions include spacecraft retention (during launch, ascent, and landing), elevation, docking, and positioning (for resupply). Although the FSS elements are being designed by RI for the EOS specifically, it seems appropriate to evaluate its applicability for use with other satellites. In the assessment of Shuttle costs for various EOS support missions, charges will presumably be assessed for all payload-associated items which are carried to orbit and returned to the ground. Several optional approaches are: a) Satellite Integral FSS - the functions nominally performed by the FSS would be assigned to the satellite structural/mechanical subsystem. b) Unique FSS - the FSS would retain its functions and perform them uniquely for the EOS c) General FSS - the FSS would retain its functions and perform them for a broad range of satellites, including EOS. As shown in Table 2-24, the choice among the three options is a complex one. A FSS uniquely designed for EOS seems the least attractive choice except that satellite weight is kept to a minimum. The primary advantage of the General FSS approach lies in the cost sharing potential between programs and the structural isolation between EOS and Shuttle which results in cost savings to both programs. These savings derive principally from the simpler test integration and checkout activities required.
Electrical Power	None	The Shuttle provisions for electrical power support to payloads are more than adequate for EOS needs. Even assuming substantial needs for other co-delivered or retrieval payloads, the 1 kw average and 1.5 kw peak power available during ascent and landing will suffice. In addition, the EOS batteries are sufficient to handle all loads from Cargo Bay door closure to on-orbit deployment.
Communications	None	With the ability of the Shuttle Orbiter to monitor and process caution and warning signals, and associated telemetry from EOS, the need for a communications relay appears unnecessary. This assumes a very low level of subsystem activity until the Orbiter has attained its parking orbit and the EOS has been elevated out of the cargo bay. With this event, more extensive activation of the subsystems will be initiated, but the higher level of activity and the more extensive need for telemetry processing can now be handled by EOS-to-ground communications. Hence, there is no shuttle related cost impact in the communications area.
Data Handling	Not Applicable	The allocation of various data handling functions between the EOS subsystems and Shuttle Orbit is confounded in part by overriding safety considerations. The provision for caution and warning (C&W) monitoring of potentially hazardous conditions on the spacecraft demands that provisions also be included for monitoring related subsystem status data and issuing related commands. Data from the SOAR and PUT studies indicate that the ratio of support functions to C&W conditions may run as high as 4 or 5 to 1. The need to monitor portions of the telemetry data stream in the Orbiter and the capability to issue some limited commands in response to C&W indications is a basic safety requirement, and is not subject to a minimal cost trade decision. This area will be more fully covered in Study Report No. 6.
Thermal Control	None	Shuttle orbiter has the capability for coolant loop thermal control of payloads; however, there appears to be no need for this type of service to EOS due to the limited orbital stay time in the payload bay and the wide range of thermal conditions tolerable by the EOS components. There is no cost impact. If the requirements for attached checkout should exceed 6-10 hours, however, some need for thermal control via attitude change may be found necessary. The same need would exist if a contingency were to prevent separation after the nominal interval.
Attitude Control	None	Precision pointing of the EOS is required for the accomplishment of certain sensor tasks. However, it has generally been decided to postpone these tasks until separation from the Orbiter has been completed. This decision also eliminates the need by the Orbiter to maintain tight stability rates, a procedure which involves substantial use of propellant. Likewise, the performance of these precision sensor tests by the free-flying EOS relieves the FSS of the need for complex and costly pointing and stability functions. The capabilities of the Shuttle-Attached Manipulator System (SAMS) is not available to any detail at present. However, the capability of the EOS propulsion and attitude control subsystems appear quite capable of countering any but the most severe rates which might be imparted by the SAMS at release. Various studies of spacecraft interfaces with Shuttle mounted and free-flying manipulator systems indicate that tip-off rates should be well within the tolerable limits. The SOAR study, in particular, has indicated that no major problem is expected. Major potential difficulties were initially pointed out for TUG-delivered spacecraft, but GE analysis for the TOPSS and PUT studies have indicated that properly designed latch systems can reduce tip-off rates to less than 0.2 degrees per second. There is no cost impact in this area.
Orbit Delivery & Retrieval	----	Costs are considered under launch vehicle section.

Table 2-24. Optional Flight Support Systems

Option	EOS Relevant Effects	Orbiter Relevant Effects	Cost Impacts
Satellite Integral FSS	o Maximum satellite weight o Simplifies EOS/Shuttle Interfaces o Total EOS/FSS weight probably minimal	o Orbiter ground C/O complexity increases	o Some cost savings over unique FSS approach o Lowest Shuttle tarrif - e.g., no FSS for down trip on EOS delivery mission.
Unique FSS	o Relatively simple EOS/ Shuttle interface o Minimum satellite weight o EOS design "drives" FSS design o EOS program takes FSS weight penalty unless up and down trips both used	o Similar to above	o Most expensive for EOS program o Independent program and duplication of costs o Shuttle tarrif penalty - $0.5-0.6M for up or down trip
General FSS	o Complex EOS/Shuttle Interfaces o Moderate Satellite weight o FSS design "drives" EOS design o EOS Program shares FSS weight and cost	o Simplest ground C/O requirements o Common interface with many satellites	o Least expensive for EOS program-shared costing with many satellites o Lowest shuttle tarrif - e.g., FSS used for EOS delivery accommodates retrieval of another satellite

2.19.1 COST/WEIGHT CRITERIA

Launch vehicles investigated for EOS-A include the Delta 2910, Delta 3910, Titan IIIB NUS and Titan IIID NUS. The cost of the Titan IIID NUS launch vehicle of $44-M per launch eliminated it immediately from further consideration. Table 2-25 summarizes their cost, spacecraft payload capability (to 400 nm altitude) and shroud volume. The added weight capability from Delta 2910 and 3910 is about 1000 lbs at a cost of $2-M or $2-K/lb.

Table 2-25. Launch Vehicle Cost, Spacecraft Weight, and Shroud Volume Comparisons

Launch Vehicle Candidate	Cost ($M)	S/C Payload Capability (lbs)	Shroud Volume (ft^3)
Delta 2910	6.0	2525	600
Delta 3910	8.0	3550	600
Titan IIIB NUS	15.5	4550	1670

2.19.2 PROPULSION SUBSYSTEM

The propulsion subsystem design, exclusive of the propellant tankage, is relatively insensitive to cost trades conducted on a weight and volume basis. Therefore, the propulsion subsystem cost trade was limited to the propellant tankage.

The propulsion system propellant tank trade was made on the basis of an EOS-A mission injected by the Delta launch vehicle and recovered by Shuttle. For a 2,200 lb EOS-A spacecraft operating at a mission altitude of 418 nm, approximately 180 lbs of hydrazine are required. The 180 lbs of propellant was used to determine the required tankage size. The cost vs. weight and volume data are plotted in Figure 2-15.

The lowest cost tankage is the two 22.14" titanium tanks. A single 29.5" titanium tank is available for an increase of about $48-K with a weight savings of about 8 lbs or $6-K/lb. Since this is greater than the $2-K/lb criteria, the two 22.14" tanks are the most cost/weight effective.

2.19.3 C&DH MODULE

The most significant element in the C&DH module affecting cost, weight, and volume is the transponder. The cost trade considered the following candidate transponders:

- ERTS Transponder
- BSE Dual M transponder
- Viking "75" transponder

Costs (based on three flights and 1 qual unit), size and weight were obtained for each of the candidate transponders and are plotted in Figure 2-16.

Considering a redundant transponder approach, the minimum cost transponder is the ERTS unit. Its cost is $200-K less than the Dual M transponder but weighs 12.5 lbs more. The difference, at $16-K/lb, is not worth the weight savings. For a non-redundant approach, the ERTS unit is also most cost/weight effective.

2.19.4 THERMAL CONTROL SUBSYSTEM

Cost, weight, and volume trades were conducted for candidate thermal control concepts. The thermal control concepts considered were:

1. Passive - insulation, coatings, heaters
2. Intermediate Radiator
3. Fluid Activated Louvers
4. Bi-Metallic Louvers
5. Heat Pipes

Detail cost/performance trades were performed and are discussed in Section 3.4.2. Information developed during these trades regarding cost, weight, and volume are plotted in Figure 2-17. All costs are for one subsystem module.

The results of the trade study show clearly the cost/weight effectiveness of the passive thermal control concept over all other concepts considered.

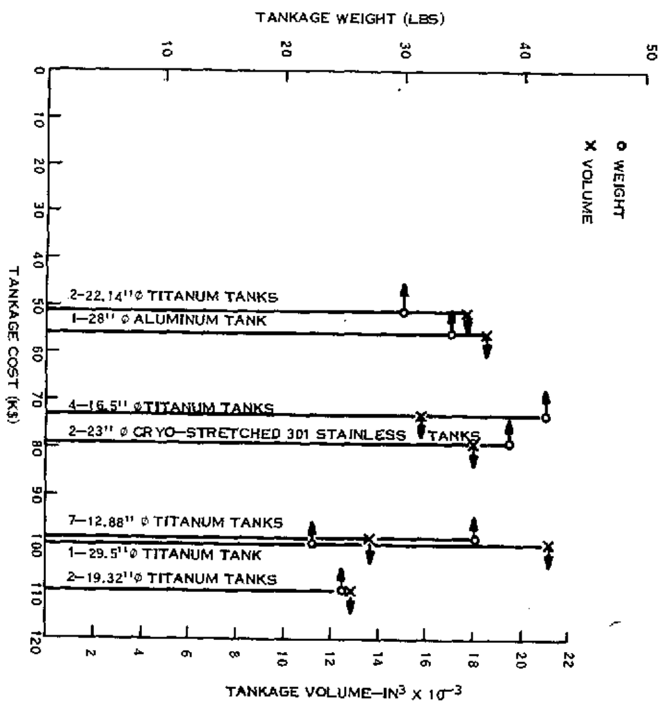


Figure 2-15. Propulsion Subsystem Tankage Weight, Volume & Cost Tradeoff

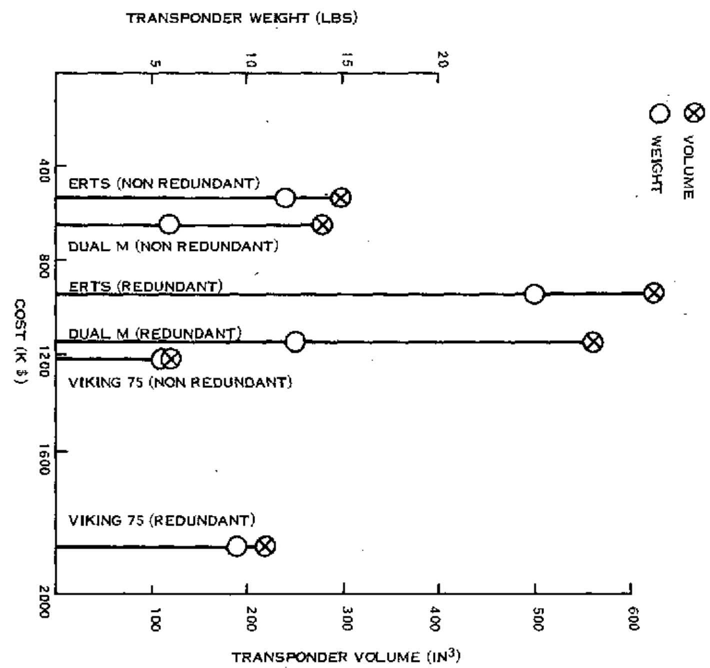


Figure 2-16. Transponder - Weight/ Volume/Cost Tradeoff

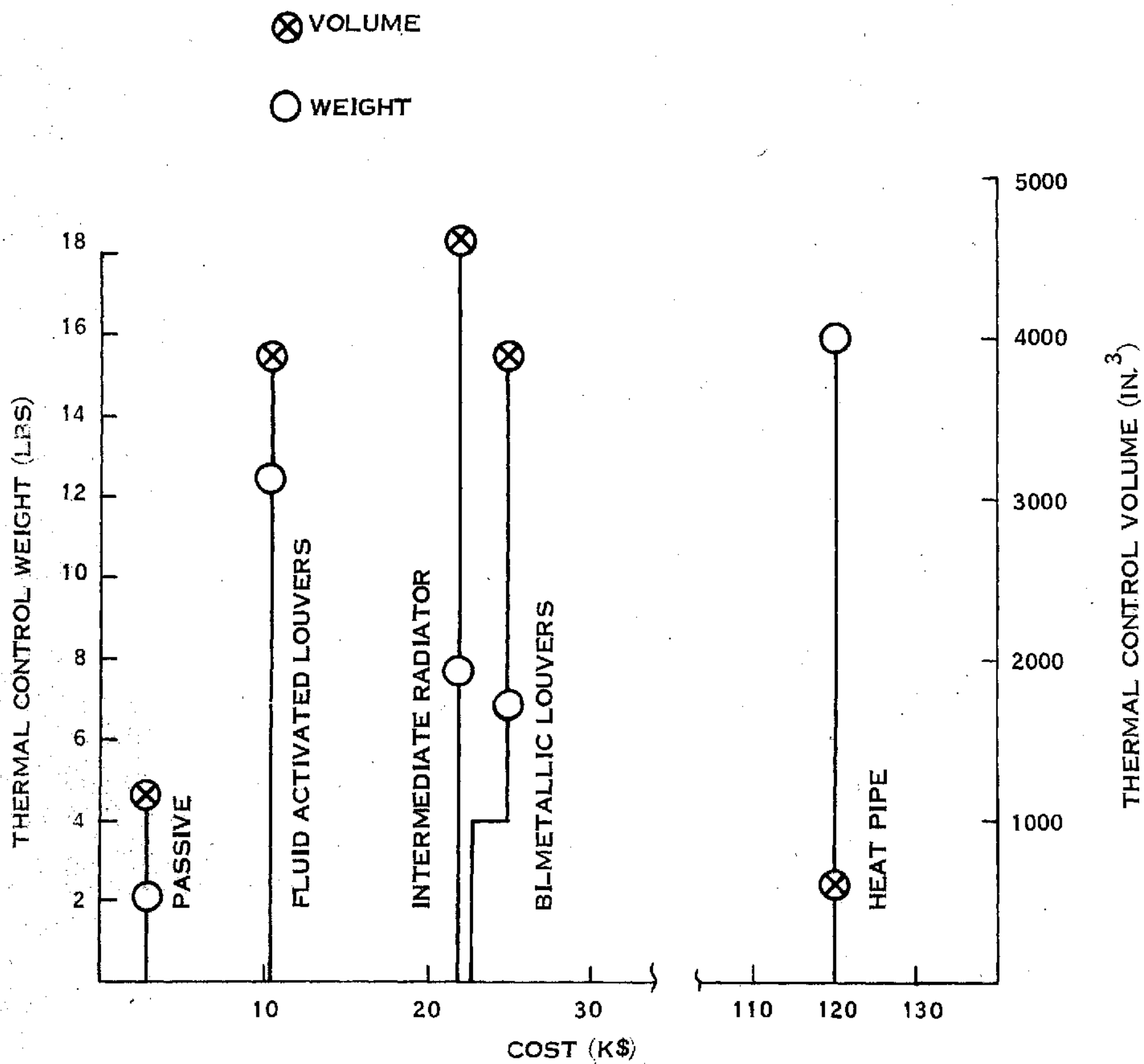


Figure 2-17. Thermal Control Weight/Volume/Cost Tradeoff

2.19.5 INTERSTAGE ADAPTER TRADES

The interstage adapter acts as the launch support for the spacecraft and incorporates mechanisms which provide separation of the spacecraft from the launch vehicle. Several candidate adapter concepts have been considered for EOS-A and have been traded off with regard to cost, weight and volume for both Delta and Titan Launch vehicles. These concepts include:

1. NASA baseline - transition ring and interstage adapter
2. Optimized NASA baseline - transition ring and integral shroud interstage
3. Conventional adapter - simplified transition ring and no interstage adapter

Cost, weight, and volume comparisons for the various adapter configurations are shown in Table 2-26. In this table, two sets of costs and weights are shown. The first set represents direct costs for the various adapter configurations. However, the use of a conventional adapter configuration results in total system cost and weight penalties. These penalties occur because the conventional adapter will require additional structure in the spacecraft subsystem to transfer spacecraft loads to the launch vehicle. The second set of costs and weights in Table 2-26 reflect the associated cost and weight penalties.

In general, it can be concluded that for both Titan and Delta launch vehicles the costs and weights for the conventional adapter configuration are significantly less than those required for the baseline configuration with transition ring. This conclusion applies both with and without additional spacecraft subsystem structure weight and cost penalties.

2.19.6 POWER SUBSYSTEM

Cost vs. weight trades within the Power Subsystem were investigated particularly with respect to the battery and solar array. These two components usually represent more than 70 percent of the total subsystem weight for low altitude missions. The electronic power control and regulation components are not as amenable to analysis nor are the potentials for weight savings as great.

Table 2-26. Adapter and Separation System Cost, Weight and Volume Comparisons

Adapter Configuration Candidate	Launch Vehicle	Cost (K$)	Weight (lbs)	Total[(1)] Cost (K$)	Total[(1)] Weight (lbs)
NASA Baseline Interstage	Titan	113.1	513	113.1	513
Optimized Interstage	Titan	115.6	513	115.6	513
Conventional	Titan	74.5	160	84.5	260
NASA Baseline Interstage	Delta	88.5	199	88.5	199
Conventional 24" Standard	Delta	25.5	83	30.5	133
Conventional 12" Standard	Delta	25.5	71	30.5	121
Integral Interstage	Delta	101.0	430	101	430

(1) Includes effect of additional cost and weight penalties resulting from additional spacecraft subsystem structure requirements

The battery design selected for the EOS mission is based on a current GE Space Division battery development program. The experience and data obtained on this program together with detailed analysis of test costs were used to calculate several points on the cost vs. weight curve shown on Figure 2-18. Minimum weight for a given battery module is very costly as can be illustrated by the steepness of the curve below 47 lbs. Thus, the design point for EOS batteries has been selected just below the knee of this curve to achieve a weight/cost optimized design.

Solar array cost/weight trades center on the effects of coverglass thickness and solar cell thickness. The baseline EOS coverglass thickness of 300 μm of fused silica could be reduced to a nominal 150 μm with a corresponding reduction in weight and increase in solar array cost. The analysis of this cost/weight factor is complicated by the fact that reduced coverglass thickness will result in more solar cell radiation damage or more array area required for a given EOM power output requirement. Using the selected EOS-A solar array design as a baseline, a comparison of radiation damage shows that 10.126 m^2 (109 ft^2) of panel area would be required for 150 μm coverglass as opposed to 9.847 m^2 (106 ft^2) for the baseline 300 μm thickness. Accounting for this size increase as well as

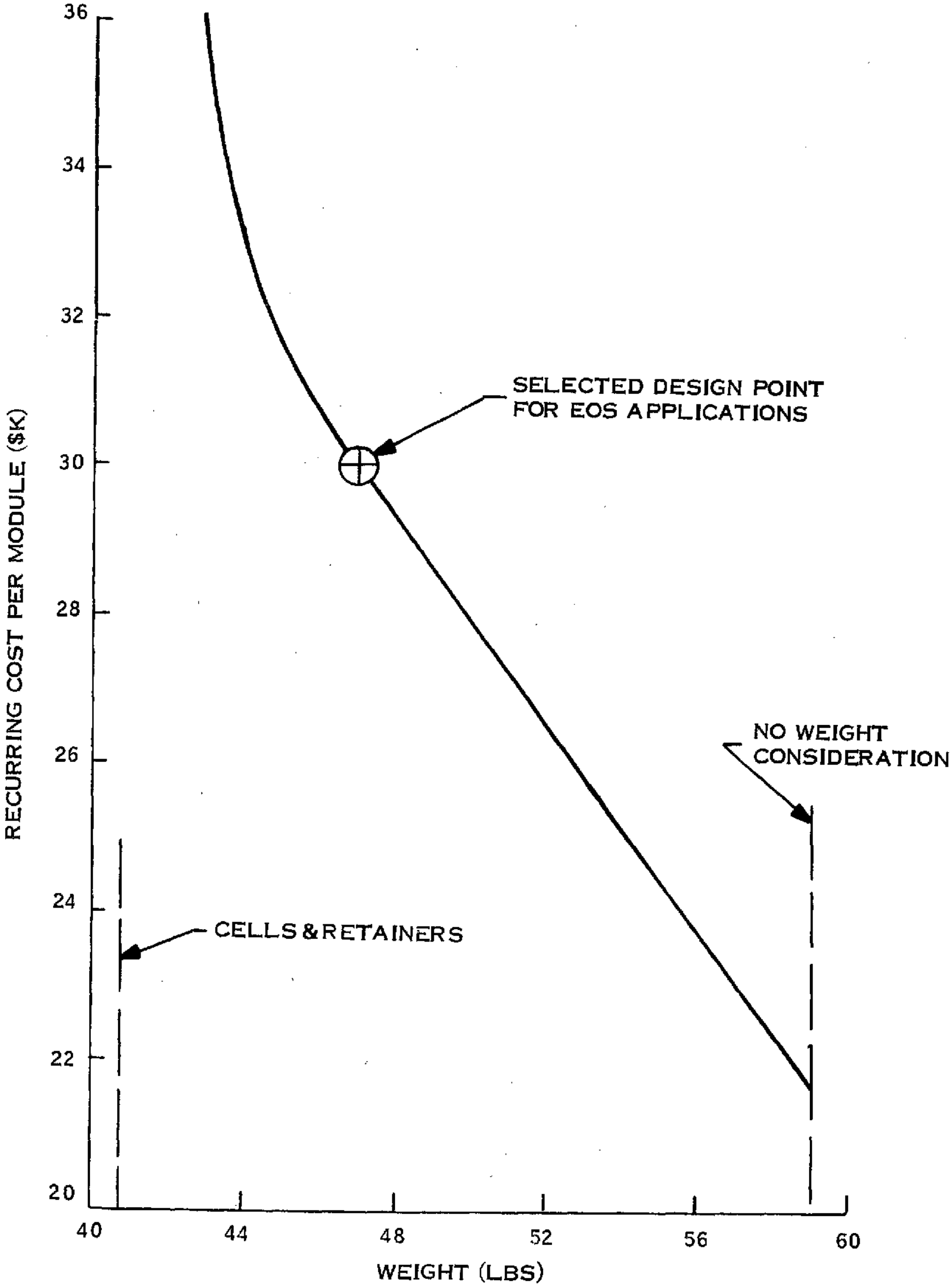


Figure 2-18. Cost vs. Weight for a 17 Cell 24 A-H Nickel Cadmium Battery

the weight difference associated with the reduced coverglass thickness yields a net weight reduction of 1.56 kg, (3.45 lb) for the solar array with 150 μm coverglass. This is based on a total unit weight of 4.882 kg/m^2 (1.00 lb/ft^2) for the baseline EOS-A solar array (including substrate). At a unit recurring cost of \$43,000/m^2 (\$4,000/ft^2) the baseline solar array will cost \$423-K per spacecraft. The reduction in coverglass thickness from 300 to 150 μm is estimated to increase the unit recurring cost by \$1076/m^2 (\$100/ft^2). These unit costs result in a net cost difference of \$22,900 per spacecraft for a reduction in weight of 1.56 kg (3.45 lb) for a resultant cost/weight factor of \$14,680/kg (\$6638/lb), making the thicker coverglass the most cost/weight effective selection.

The evaluation of the cost/weight trade for solar cell thickness is quite complicated due to the influences of thickness on both initial electrical output and radiation damage. It is expected that the resultant cost/weight factor will be of the same order of magnitude as the factor calculated for changes in coverglass thickness. This should be true for changes in solar cell thickness between 350 and 200 μm. Below 200 μm thickness the cost/weight ratio should increase rapidly.

SECTION 3

SPACECRAFT SUBSYSTEM COST TRADEOFFS

This section describes the design/cost tradeoffs within the various spacecraft subsystems. In addition, it provides cost elements within the various subsystems that are traded at the system level (in Section 2).

The section is organized into the following subsystem or technology areas:

- Mechanical. Including instrument, spacecraft and module structures; mechanisms; and interstage adapter/transition ring.
- Thermal. Includes instrument, spacecraft and module thermal control.
- Propulsion. Including orbit transfer, orbit adjust and reaction control systems.
- Wideband Data Handling. Including payload data processing, recording and communication equipment.
- Power Module. Including solar array and all power conditioning and storage equipment.
- ACS Module. Including sensors, reaction devices except mass expulsion and interface electronics.
- C&DH Module. Including all equipment for housekeeping telemetry, tracking, command and on-board computation and storage exclusive of payload (wideband) data and the on-board software required to support these functions.

For convenience both mission peculiar and non-mission peculiar considerations are treated in the above areas.

Subsystem requirements and descriptions are given only as necessary to adequately define and evaluate the cost tradeoffs discussed. For brevity, areas where no significant cost trades were identified have been omitted.

3.1 MECHANICAL DESIGN/COST TRADEOFFS

This section considers three cost trade areas that can be primarily evaluated within the mechanical/structural area. These are (1) alternative structural designs, (2) alternative interstage adapter and transition ring concepts, and (3) the use of standard actuators for mechanism designs. These are discussed in Sections 3.1.1 through 3.1.3 respectively. The cost impact within the structural/mechanical area of several system level cost trades are discussed beginning with Section 3.1.4. They include:

- Impact of TDRS.
- Impact of solar array designs.
- Impact of TM/HRPI approach.
- Impact of Shuttle retrieve/resupply.
- Follow-on instrument accommodations.

3.1.1 STRUCTURAL DESIGN ALTERNATIVES

Structural cost/weight evaluations have been made for the EOS-A Titan/Shuttle configuration using two construction techniques shown in Figures 3-1 and 3-2, respectively. Both configurations feature a central transition ring supporting the subsystem and instrument section structures and interfacing at the forward end of the cylindrical interstage adapter for a Titan launch. For a Shuttle launch or retrieval the spacecraft is clamped circumferentially at the transition ring by the Shuttle Flight Support System cradle. The tradeoff is considered directly applicable to the Delta Configurations as well.

The following design/cost comparisons of these structures compared welded 6061 aluminum truss construction for the Baseline and 2024 aluminum semi-moncoque construction for the alternate. Table 3-1 summarizes the launch vehicle load factors. An assessment of structural weights using a limit working stress of 15 KSI for strength, or providing a lateral natural frequency of 10 Hz indicates structural weights for either arrangement will be comparable to the type of construction selected will be primarily dependent on cost alone. Costs have been estimated for fabrication of one unit and include materials, purchased parts, shop

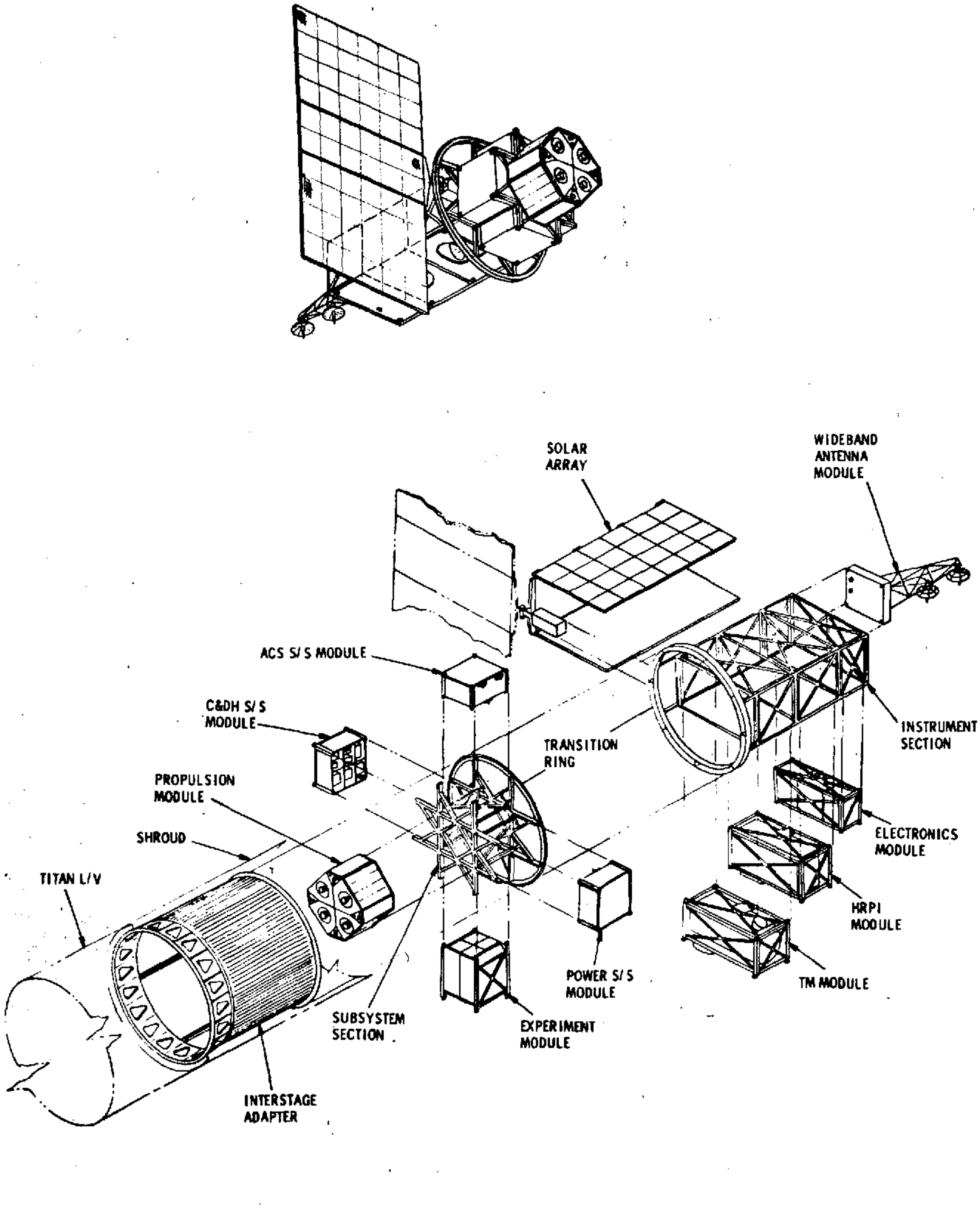


Figure 3-1. EOS-A Baseline Titan/Shuttle Configuration

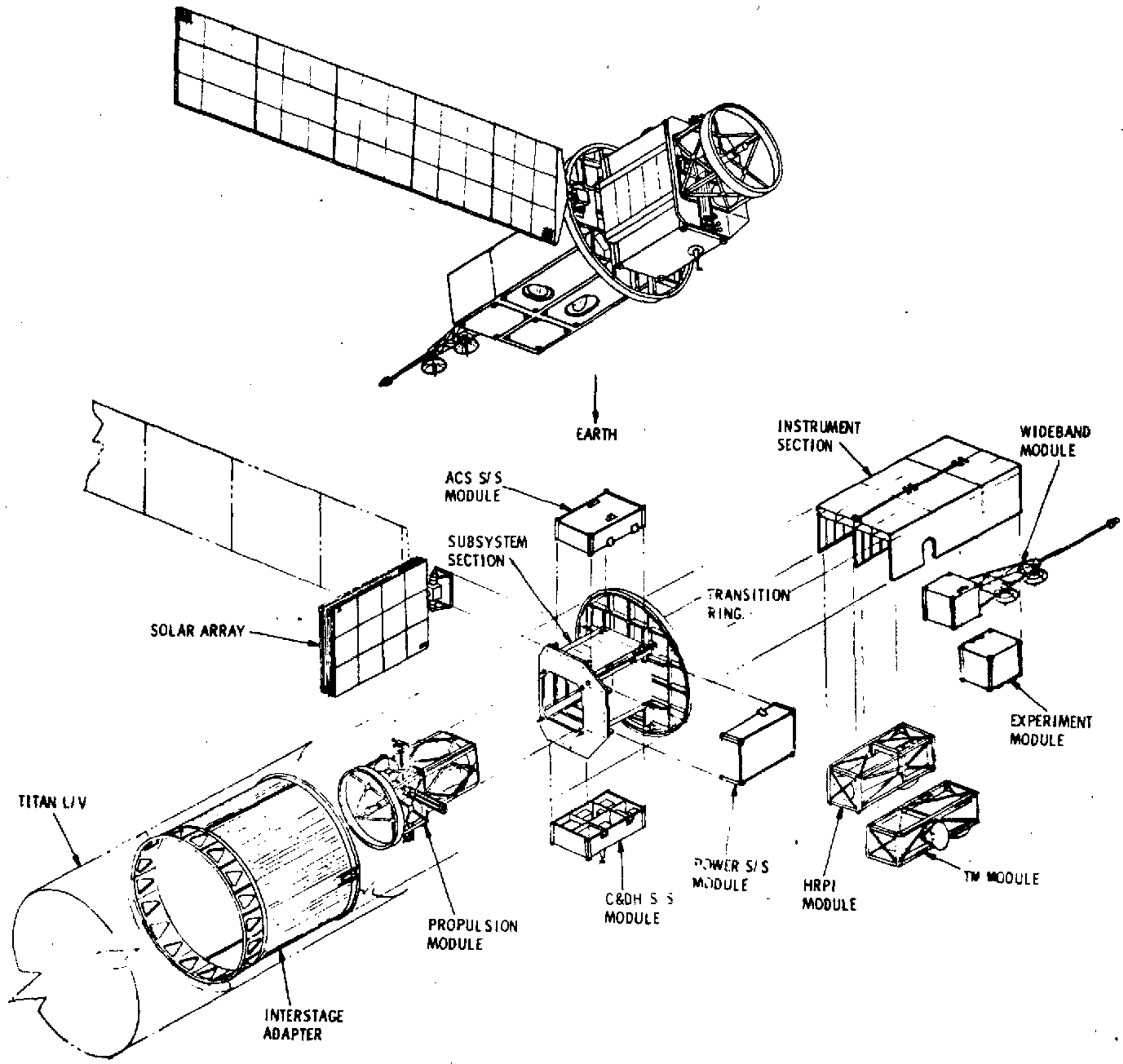


Figure 3-2. EOS-A Alternate Titan/Shuttle Configuration

labor and tooling costs. Design and analysis costs are considered equivalent for either configuration or type of construction and a common module latching mechanism has been assumed applicable to either design and those costs are not included.

Table 3-1. Structural Requirements Summary

Spacecraft Qualification Test Levels (1.5 X Expected Level)										
Launch System	Accelerations (g's) Thrust	Accelerations (g's) Lateral	Random Vib. (g rms)	Max. Sine Vib. (g's) Thrust	Max. Sine Vib. (g's) Lateral	Acoustics dB	Shock Resp. (g's Max.)	S/C Load Factor	S/C Ultimate Design Loads (g's) Thrust	S/C Ultimate Design Loads (g's) Lateral
Delta	- 18.0	± 3.0	11.3	6.8	2.0	144	1700	1.25	-22.5	3.75
Titan III D	- 9.0	± 2.6	16.9	3.0	2.0	147	3500	2.0	-18.0	5.2
Shuttle										
L/O	- 3.45	1.28	7.9 to	TBD	TBD	143 to	TBD	2.0	- 6.9	2.56
B/O	- 4.95	.81	24.3			149		(1.2	- 9.9	1.61
Entry	± .38	4.56						crash)	± ..76	9.12
Ldg	± 2.25	4.37							± 4.5	8.74
Crash	+ 9.0	4.5							+10.8	5.4

<u>Subsystem Section Structure</u> (Figure 3-3). The Baseline Subsystem support structure consists of planar welded 6061 aluminum alloy truss sections bolted together to form a rectangular open box structure. The lower (earth viewing) surface is open to accommodate a central experiment module, and the three subsystem modules are installed on the side and upper box surfaces, attached by a common latching mechanism and guide rail at each module corner.

The alternate semi-monocoque structure consists of a central closed box with four primary longerons at the box corners. The transition ring forms the forward bulkhead and an open center aft bulkhead completes the structure. (The aft bulkhead central opening is closed by the propulsion module central bulkhead.)

Construction is of straight-formed and extruded 2024 aluminum sections and flat aluminum sheet panels riveted and bolted to form the stiffened sheet structure. The subsystem modules are attached to the upper and lower and to one side of the box structure using a common corner latching mechanism.

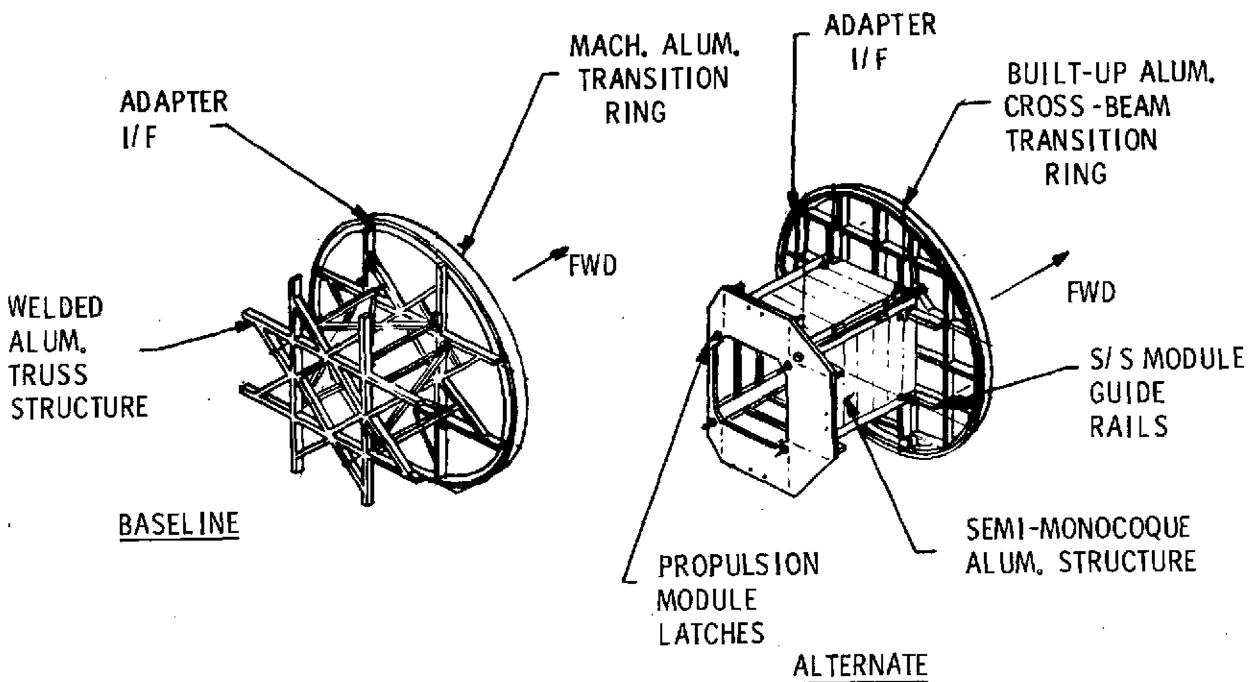


Figure 3-3. Subsystem Section Structure

Estimated costs for these designs are:

	Baseline K$	Alternate K$
Materials	2.0	1.0
Tooling	2.7	3.0
Labor	18.0	18.0
Total	22.7	22.0

These costs are virtually identical and indicate either type of construction can be used effectively for this section.

Transition Ring. Baseline and alternate ring designs are shown on Figure 3-4, and have been evaluated for weight and cost. Weights for either design are comparable and costs of the built-up alternate design are somewhat higher due to higher assembly labor. Estimated costs are:

	Baseline K$	Alternate K$
Materials	9.0	9.5
Tooling	2.5	3.5
Labor	8.5	13.0
Total	20.0	26.0

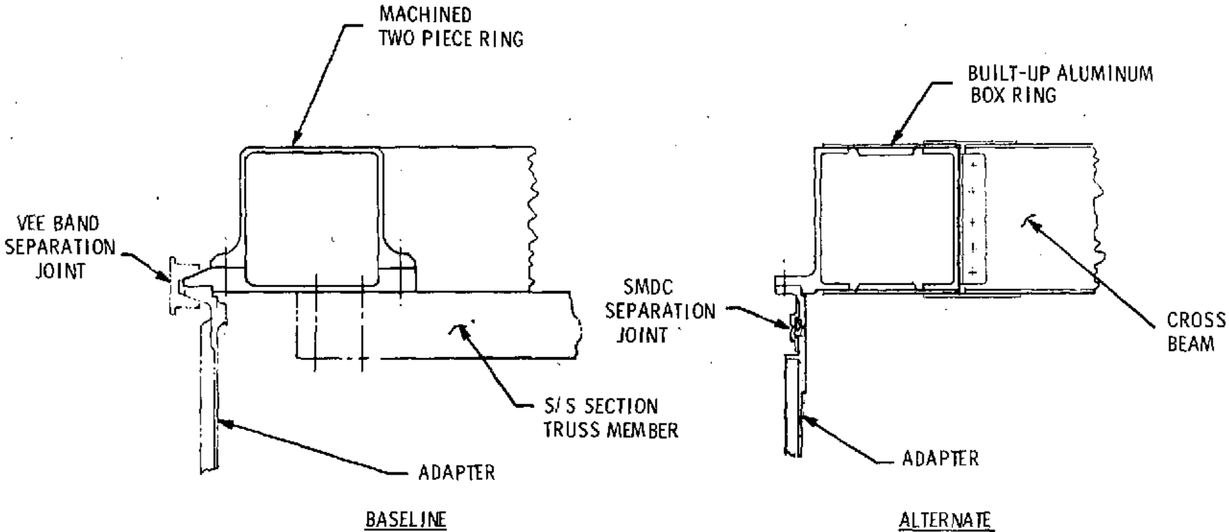


Figure 3-4. Transition Ring Designs

Subsystem Module Structure. The baseline module structure uses a welded 6061 truss outer frame to support an aluminum honeycomb sandwich outer panel, and the first alternate design has a stiffened sheet frame and a machined integrally stiffened aluminum panel (see Figure 3-5). The second alternate module design shown on Figure 3-6 uses an aluminum honeycomb panel and stiffened sheet outer frame. This module has the subsystem components and internal bulkheads attached directly to the outer panel which is in turn attached to the open frame box structure. This approach permits use of one box frame design for all modules with components mounted to the stiffened outer panel "breadboard" resulting in simplified installation and harnessing of the modules.

Costs of these designs are:

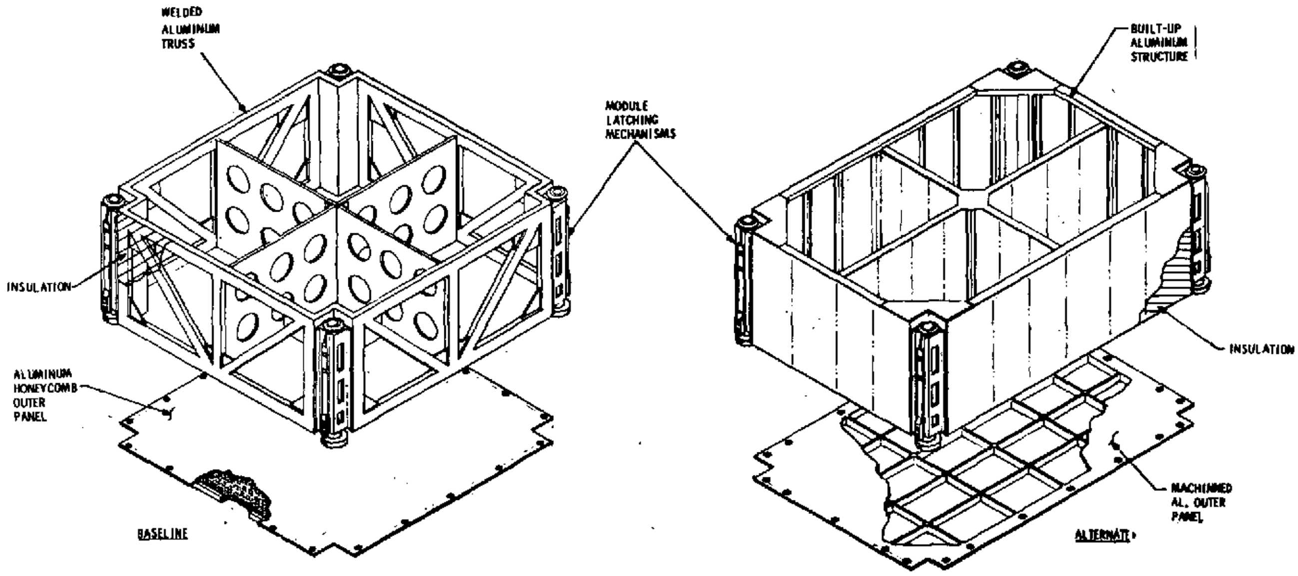


Figure 3-5. Subsystem Module Structures

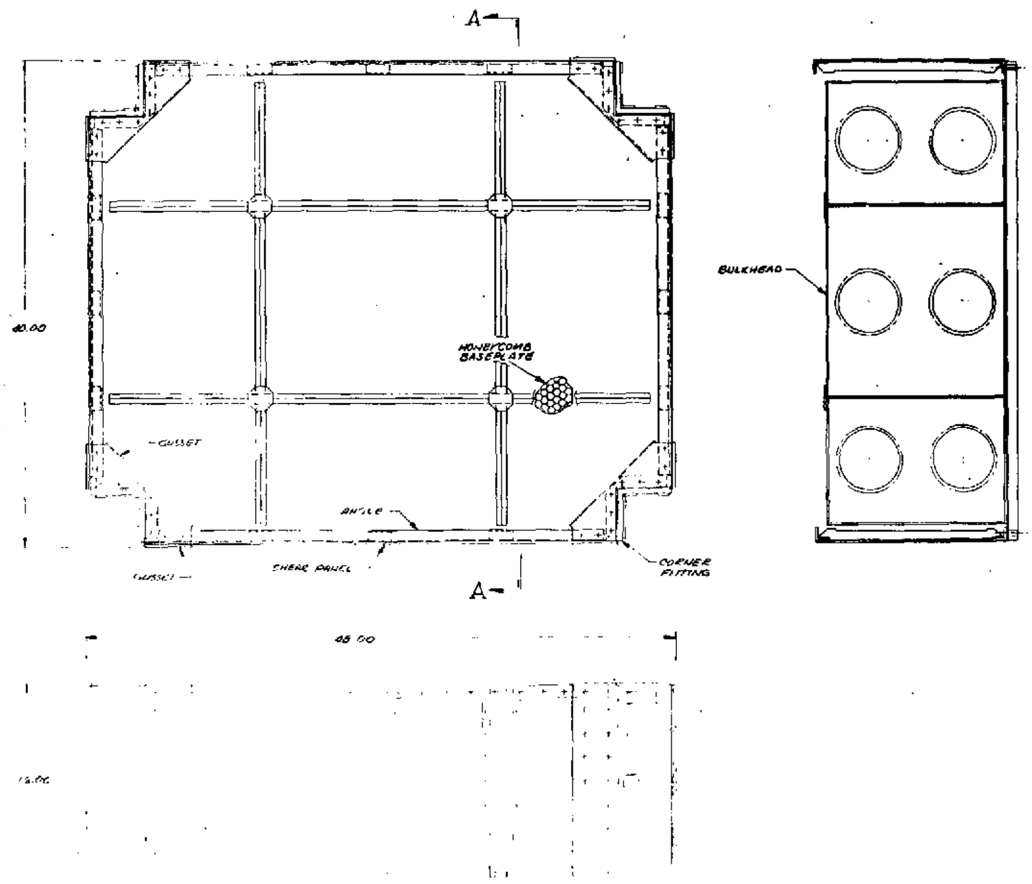


Figure 3-6. Integral Panel Subsystem Module

	Baseline K$	Alternate K$
Material	1.5	.7
Tooling	3.2	3.5
Labor	2.4	3.3
Total	7.1	7.5

Instrument Section Structure (Figure 3-7). Baseline instrument section structure is of weld ed 6061 aluminum open truss construction and the alternate design is a build-up 2024 deck structure with side and intermediate support keels. The design of this section is mission de pendent and the structural arrangement will be tailored dependent on the size, location and orientation of the instruments and equipment. All external surfaces will be insulated to pro vide independent thermal isolation for each instrument. Cost comparisons of these structur are:

	Baseline K$	Alternate K$
Material	2.0	1.5
Tooling	9.0	10.0
Labor	9.0	15.0
	20.0	26.5

These costs show some cost advantage for the truss structure due primarily to the use of fewer piece parts simplifying assembly of the section.

Propulsion Module Structure (Figure 3-8). The baseline propulsion module structure is a semi-monocoque aluminum structure. The module design for the alternate all hydrazine sys tem is an aluminum truss structure. The weight of the two structures is nearly the same, although the total module weight of the alternate design is less.

	Baseline K$	Alternate K$
Material	.4	.7
Tooling	5.5	8.6
Labor	14.4	12.0
Total	20.3	21.3

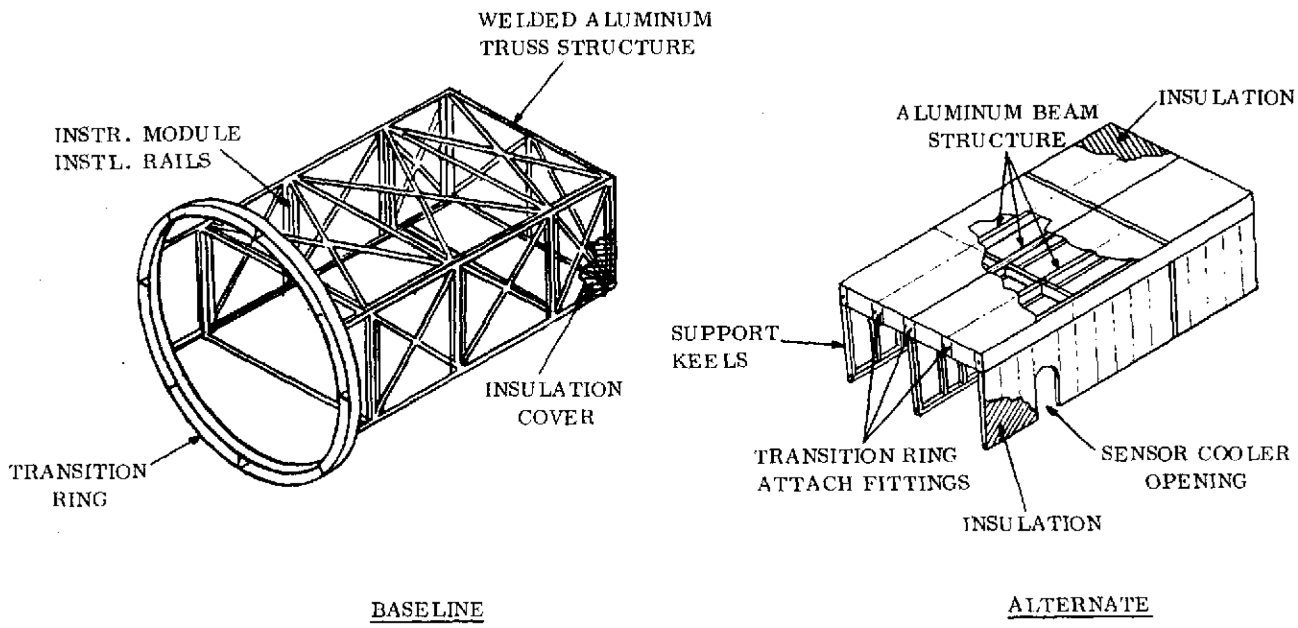


Figure 3-7. Titan/Shuttle Instrument Section Structure

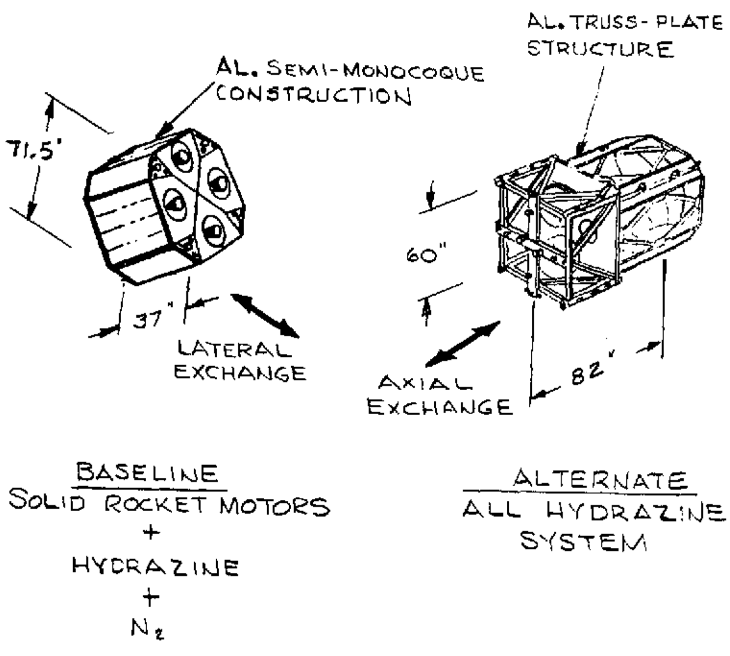


Figure 3-8. Propulsion Module Structures

Conclusions. The preceding cost analysis shows that, given similar structural arrangements and using standard aluminum materials, there is very little cost differential between welded truss and semi-monocoque construction. The truss structure for the payload sections and the machined forging for the transition ring are the only areas where a significant cost difference exists. Thus, there is considerable latitude in the structural design in that the type of construction most advantageous to the application for weight, space or mounting can be used at the designer's discretion.

3.1.2 INTERSTAGE ADAPTER/TRANSITION RING

The interstage adapter acts as the launch support for the spacecraft and incorporates separation mechanisms which allow separation of the spacecraft from the launch vehicle once orbit altitude is achieved. The transition ring separates the mission peculiar equipment from the basic spacecraft and is used for shuttle retrieval. Both the transition ring and interstage adapter are mission peculiar hardware which require separate designs for the alternate launch vehicles. Four alternate concepts have been considered for EOS:

1. NASA Baseline - transition ring and interstage adapter
2. NASA Baseline - with alternate separation technique
3. Alternate No. 1 - transistion ring and integral shroud interstage
4. Alternate No. 2 - conventional aft adapter

These alternate concepts are shown in Figure 3-9 and discussed below.

NASA Baseline - Transition Ring and Interstage Adapter. The NASA baseline interstage adapter concept uses an interstage adapter that ties from the transition ring to the launch vehicle interface aft of the subsystem section. The major characteristics of this design are:

1. Experiment section and subsystem section are decoupled from each other during launch (loads from each section are carried to the transition ring and down the interstage adapter).

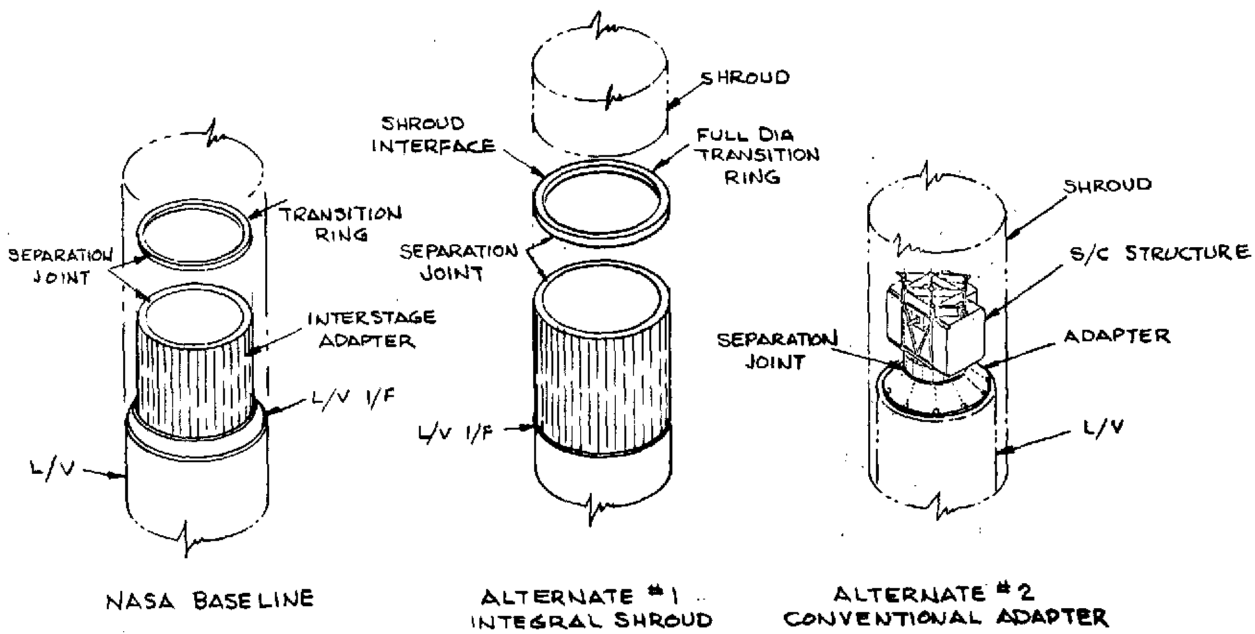


Figure 3-9. Alternate Adapter Concepts

2. An interstage is required between the shroud and subsystem section (limits the allowable diameter of the subsystem section, requires parallel load carrying structure which is not lightest weight).

3. A SMDC circumferential separation joint or Vee band is used aft of the transition ring to provide spacecraft/launch vehicle separation.

4. Separation rails are required to guide the subsystem section out of the interstage adapter.

Figure 3-10 shows the NSAS baseline interstage adapters for Titan and Delta Launch Vehicles, construction, method of separation near the transition ring, separation rail concepts and interface to the launch vehicle at the aft end of the adapter.

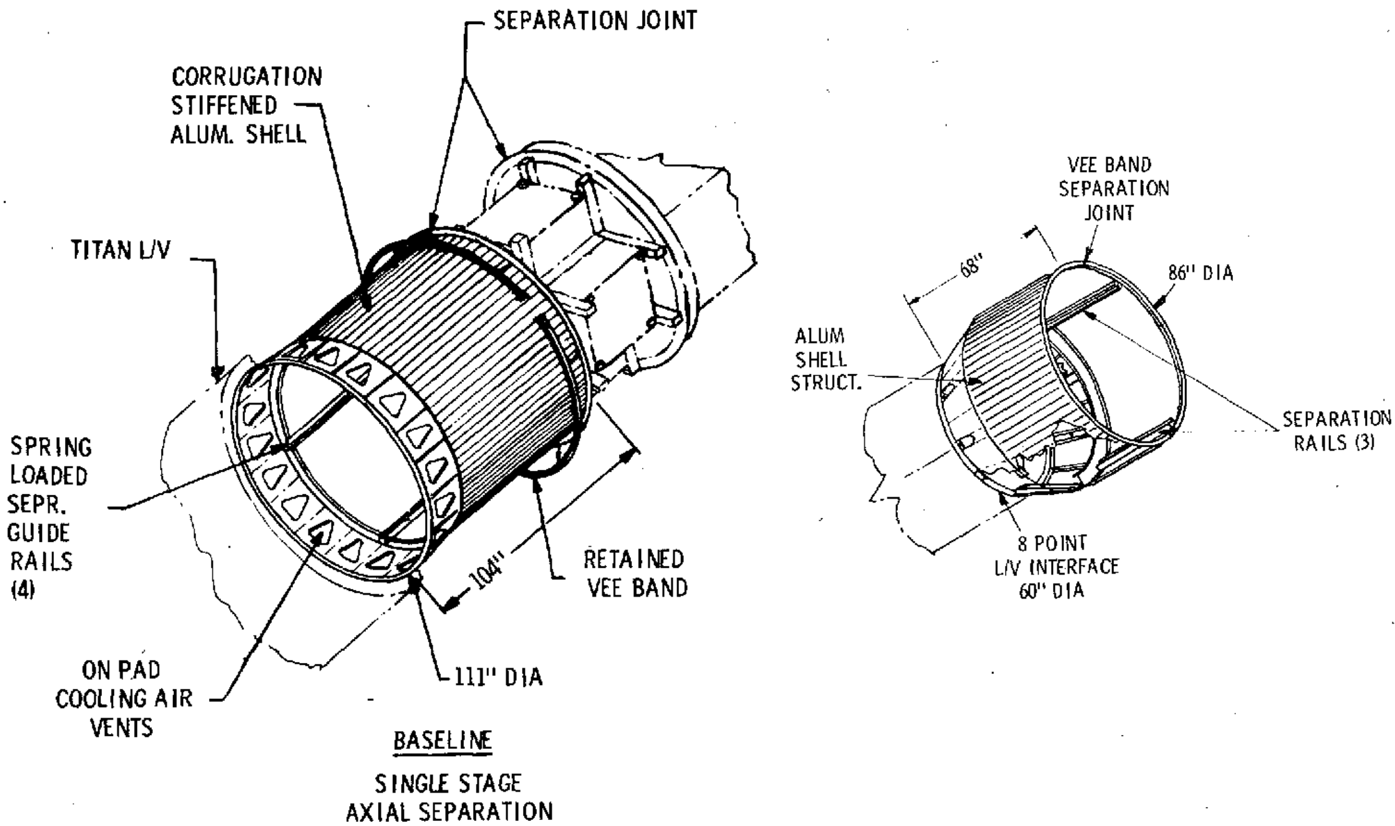


Figure 3-10. Baseline Adapters

NASA Baseline - With Alternate Separation Techniques. The alternate interstage adapter shown in Figure 3-11 uses identical structure to the NASE baseline. An alternate separation method and sequence using developed LMSC shroud devices and techniques is used. This concept is applicable to either Titan or Delta configurations.

This method first separates the spacecraft from the booster at an aft circumferential joint near the booster interface. Separation springs on the fixed section provide the required separation velocity to the spacecraft.

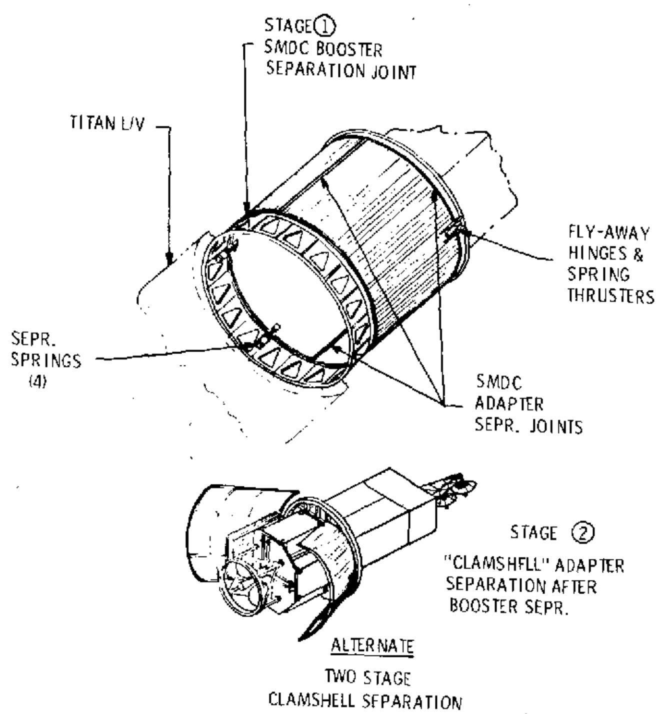


Figure 3-11. Alternate Interstage Adapter

The shroud is next simultaneously separated into two halves by two longitudinal and the forward circumferential joints, and is opened by spring activated fly-away hinge fittings and ejected. This "clamshell" separation is identical to that employed by the LMSC shroud and eliminates the need for separation rails to insure that clearances are maintained during a long axial separation.

Alternate No. 1 - Transition Ring and Integral Shroud Interstage. Figure 3-12 illustrates a system that does not require the separate interstage adapter thus providing additional volume for the subsystem section. The shroud is divided into an upper section and a lower section. The upper shroud interfaces with the forward end of the transition ring and is jettisoned similar to the present Titan shrouds. The lower shroud section attaches to the aft face of the transition ring and acts as a combined interstage and shroud, carrying all loads (air and inertial) from the transition ring to the launch vehicle interface. The shroud separates from the launch vehicle at the lower end and then clamshells off from the transition ring; therefore, it is not necessary to draw the subsystem section out of a long cylinder. The major disadvantage of this system is the integration required between launch vehicle shroud contractor and the spacecraft contractor to define the hardware implementation and analyze the combined loads for the shroud interstage. This type system is being investigated by MDAC for application with the Delta launch. Their preliminary estimate is a 400 pound weight penalty for the integrated shroud/interstage.

Alternate No. 2 - Conventional Aft Adapter. The conventional adapter concepts shown on Figure 3-13 for Titan and Delta configurations ties the aft end of the subsystem section to the launch vehicle through a conventional adapter. The subsystem section structure is required to act as the primary load path for equipment forward of the transition ring. This concept eliminates the large interstage adapter, and simplifies the transition ring design (still required for shuttle interface) allowing additional weight margin for conventional launch vehicle applications. The conventional adapters both employ Vee band joints and spring cartidges for separation. This concept requires the subsystem section structure to be designed to transmit all spacecraft body load to the adapter and to provide the primary structural stiffness during launch. These requirements will result in a heavier subsystem section but will result in a lighter overall spacecraft structure.

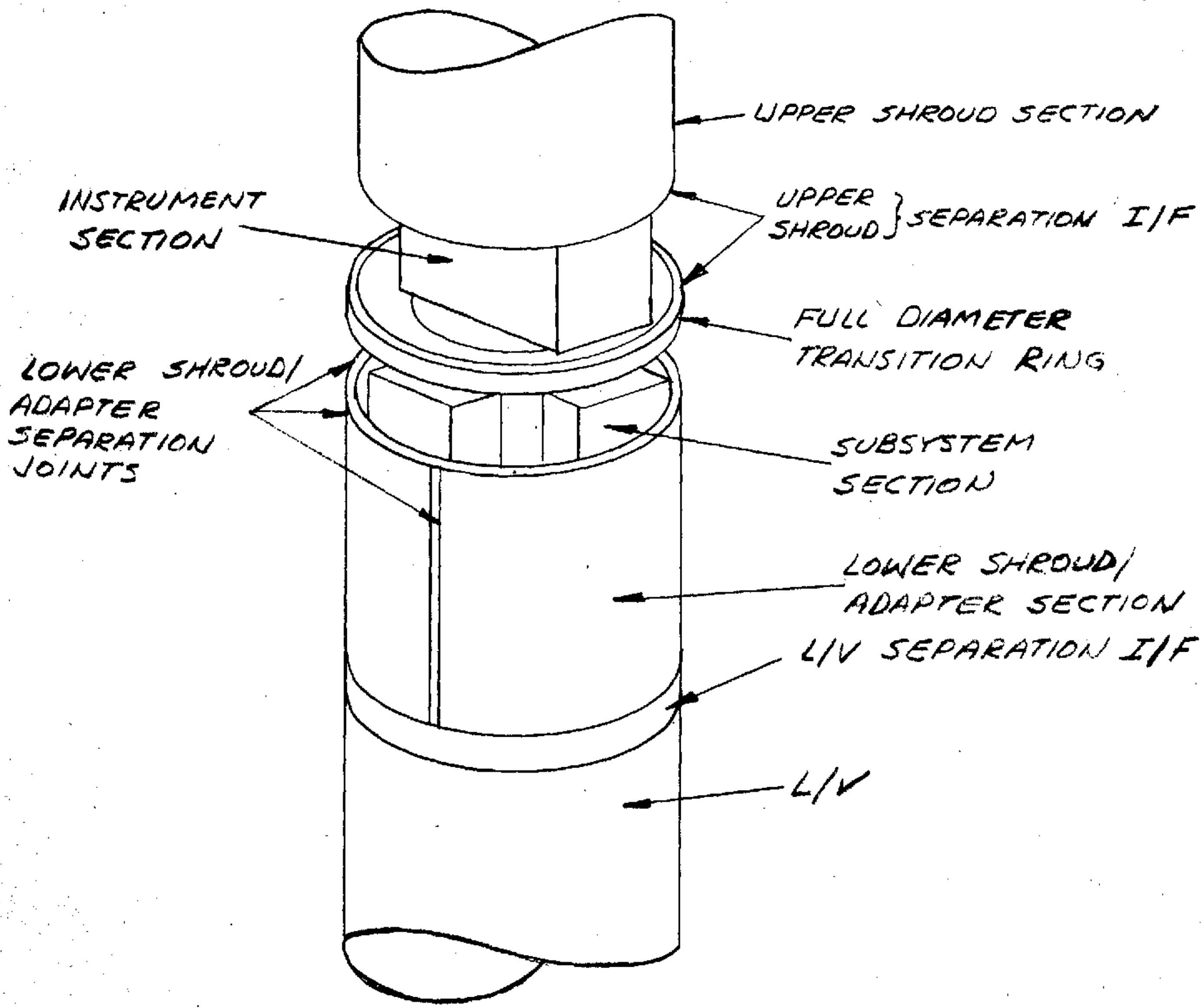


Figure 3-12. Integral Shroud/Interstage Adapter

A transition frame is located between the subsystem and instrument sections to permit three point attachment to the Shuttle retention cradle for launch or retrieval by Shuttle.

Design/Cost Comparisons. A comparison chart for the Adapter Rings and Separation Systems is shown in Table 3-2. Costs shown are manufacturing estimates for one system including tooling, materials, and shop labor. Engineering and development test costs are assumed equivalent and are not included. Weights have been estimated for each L/V application based on maximum payload capability for each booster. A weight and cost penalty for added structure in the Subsystem Section has been included for the conventional adapter approaches,

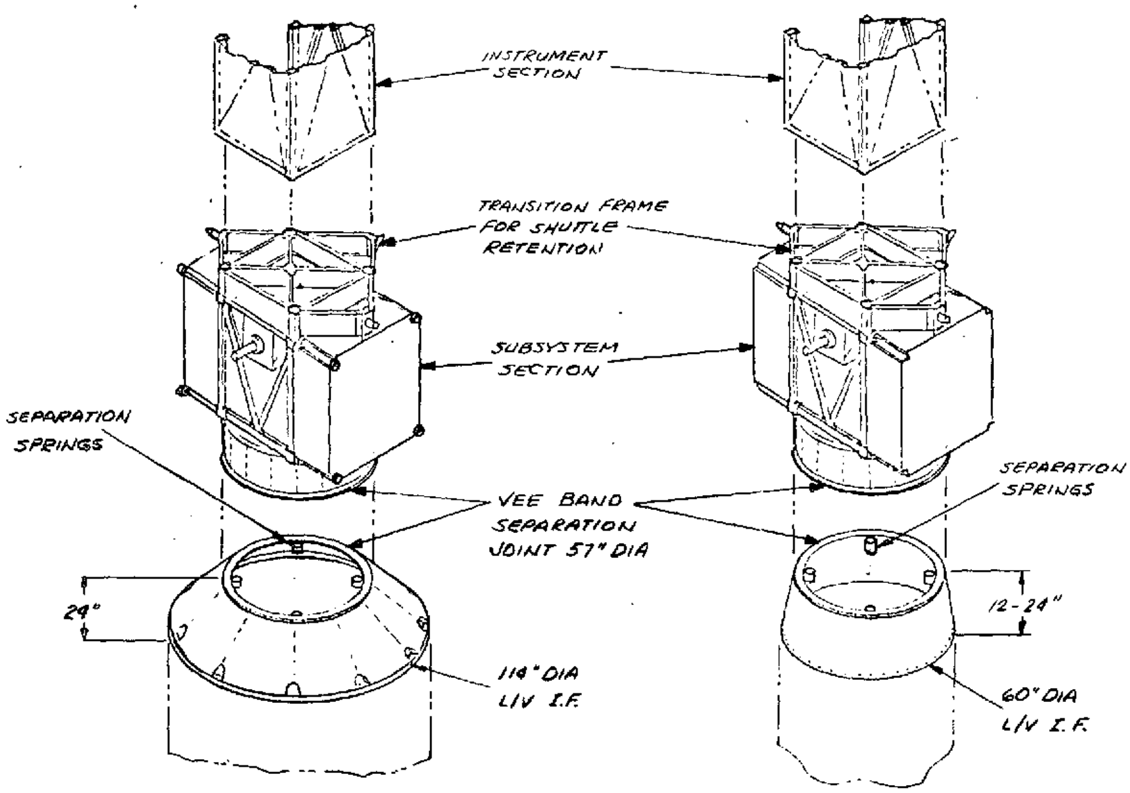


Figure 3-13. Alternate Conventional Adapters

and data for the Integral Interstage design has been taken from a preliminary MDAC evaluation of this concept for Delta. Potential cost and weight savings on the Shuttle FSS have not been assessed at this time and are not included.

The relative separation complexity has been derived considering the number of separation events and overall separation mechanism complexity for each application. The conventional adapter using standard Vee-band and separation springs at the interface joint is the most simple and reliable of the systems considered, and is rated lowest in overall complexity. The clam-shell approach using separate events for booster and adapter separations is rated next since this concept uses developed concepts and eliminates the clearance problems associated with

Table 3-2. Adapter Design/Cost Summary

L/V	Adapter Configuration	Surface Area Ft^2	Struct. Weight Lbs	Struct. Wt./Ft^2 #/Ft.^{2}	Sepr. Syst. Wt.-Lbs.	(1) Transition Sect. Wt.-Lbs	(2) Body Struct. Penalty Wt.	Total System Wt.-Lbs	Relative Separation Complexity	Relative Interface Complexity	Adapter Structure Cost K	Sepr. Cost K	Trans. Ring/Frame Cost K	Tooling Cost K	Added (2) Body Struct.	(4) Total Cost K
Titan	NASA Baseline Interstage	250	386	1.55	Band 47 127 Rails 80	250 (Ring)	0	763	4	2	97.4	15.7	20.0	30.0	-0-	163.1
Titan	Optimized Interstage	250	386	1.55	SMDC 83 127 Mech 44	250 (Ring)	0	763	3	2	97.4	18.2	26.0	30.0	-0-	171.6
Titan	Alternate Conventional	64	125	1.95	Band 15 35 Mech 20	250 (Frame)	100	410	2	3	66.0	8.5	12.5	20.0	10.0	117.0
Delta	NASA Baseline Interstage	133	139	1.20	Band 18 40 Rails 22	124 (Ring)	0	323	4	2	76.0	12.5	16.0	23.0	-0-	124.0
Delta	Alternate Conventional 24" Standard	16	56	1.74	Band 12 27 Mech 15	100 (Frame)	50	233	2	3	20.0	5.5	10.0	20.0	5.0	60.5
Delta	Alternate Conventional 12"	16	44	2.75	Band 12 27 Mech 15	100 (Frame)	50	221	2	3	20.0	5.5	10.0	18.0	5.0	58.5
Delta	Integral Interstage (3)	257	400	1.56	30	150 Est. for 96" Dia.	0	550	3	3	85.0	16.0	24.0	25.0	-0-	150.0

(1) Transition Ring or Frame for Attachment to Shuttle for launch or retrieval
(2) Added weight and cost in S/S support structure to accommodate carrying body loads thru section
(3) Weight per MDAC letter dated 5-20-74. Costs estimated proportional to optimized interstage
(4) Preliminary Cost Estimates for one unit

Highest Ranking

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long separation rails. The Baseline axial separation concept is rated most complex due to the complexity of the spring-loaded rail system controlling the separation.

Interface complexity has been evaluated as superior for the Interstage Adapter concepts since the Instrument and Subsystem sections are separated permitting relatively independent design, development and test of these sections. The Alternate conventional and Integral Interstage approaches both result in added interaction between Sections and are rated more complex than the Interstage design. Note that all of these arrangements physically separate the Instrument and Subsystem Sections into two separate modular sections.

Conclusions. The design/cost summary presented in Table 3-2 shows the conventional adapter superior from weight, cost and separation standpoints for either Titan or Delta applications. The Interstage Adapter designs are superior in regard to simplicity of interfaces and are attractive from a system design standpoint if weight is available for their use. The Integral Shroud Concept is highest in weight and cost and does not appear to be a desirable contender for the EOS application.

The conventional adapter is recommended for either a Delta or Titan launched spacecraft to provide adequate payload weight capability and margin.

3.1.3 STANDARDIZED ACTUATORS

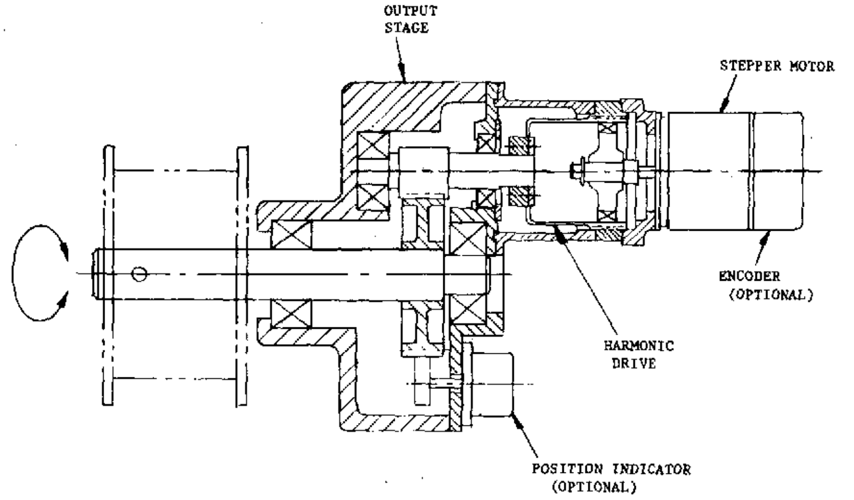
There are a number of rotary and linear actuations required on the EOS spacecraft for such functions as solar array retention and deployment, antenna deployment and gimbal drives. The development of three standard actuators has been evaluated as custom designs for these tasks. Excess size and weight, in some cases, must be traded off for the cost benefits of using a standard device.

Three standard actuators have been considered (see Figure 3-14).

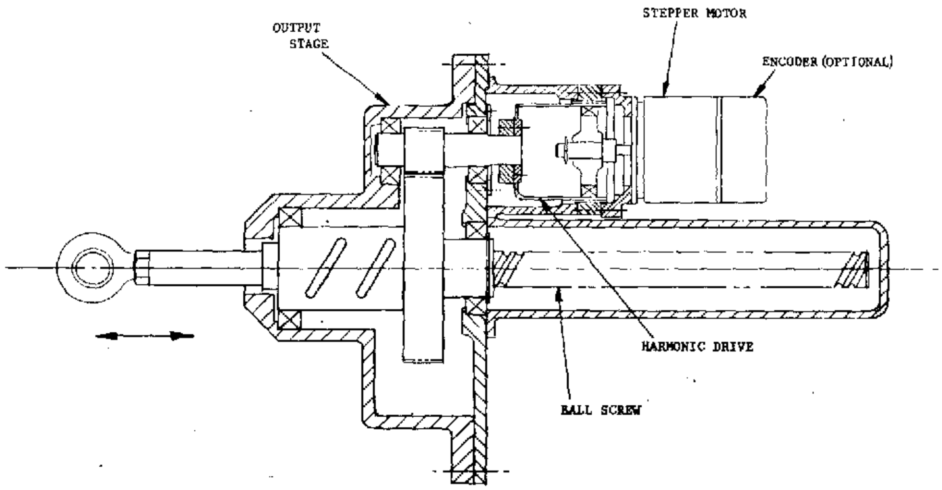
Type A Actuator - Rotary

Type B Actuator - Linear

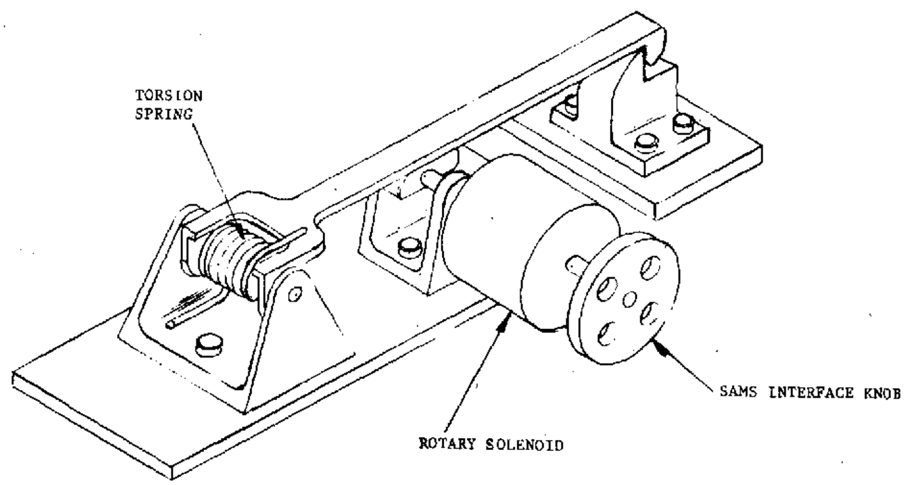
Type C Actuator - Hinge/Latch Release



Type A Rotary Actuator



Type B Linear Actuator



Type C Remote Latch Mechanism

Figure 3-14. Standardized Actuators

Type A and B actuators both use a stepper motor and harmonic speed reducer which has been developed for long life space applications. The output stage of the Type A actuator is a rotating shaft. The output stage of the Type B actuator is a shaft with axial motion only. The Type C actuator is a latching and release device which causes the latch to open with a rotary solenoid and/or sets the latch up for the subsequent latching operations upon command. It has an optional feature of being operable by SAMS using an exterior rotary knob.

Table 3-3 shows typical output performance and possible applications of these devices.

Table 3-3. Actuator Performance Requirements

Actuator	Output Speed	Output Torque	Application
Type A (Rotary)	9^o/sec	6 ft lb	Array Extend/Retract
Type B (Linear)	3"/min	600 lb	(1) Array Deployment (1) Tdr. Ant. Deployment (1) Wide Band Ant. Deploy (1) SAR Deployment (4) Instrument Cover Actuator
Type C (Latch/Release)	10 lb Release Force		(4) Array Launch Retention (4) Array Hinge Latch Release (2) SAR Latch Release (2) Wide Band Ant Stow/Lock (2) Tdr. Lock Release

The standardized actuator designs, described herein, in essence carry the modular concept of the spacecraft into the area of mechanisms. The Type A and Type B units are designed to have a motor stage and an intermediate gear stage basically identical to these two parts in the solar array drive. The actuator is completed by adding either a rotary or a linear output stage. A fitting in the output lange provides for the addition of a feedback or position indicating potentiometer as may be required. Output forces, torques, and speeds can be sized in most cases to handle a number of applications, using the step rate (pulse per second) to the motor as a control variable for specific functions.

The stepper motor/harmonic drive combination has some significant advantages, namely:

- Controllable speed
- Finite rotation even with open loop control
- Ability to hold load in position without applied power
- Compact and low weight
- Low power requirements.

The Type C (latch release) device is designed to provide a simple means of opening a spring closed latch with a common approved and available device, the rotary solenoid. By providing a ratchet effect in the cam drive, it can hold the latch open or closed without power and requires only one or two pulses to change state. These types of solenoids have been used on Apollo with success and will be used on the Soyuz mission.

A summary of this cost saving breakdown is shown in Table 3-4. These savings are made up of costs saved in the smaller number of component designs to be made and qualified, the cost break from purchase of larger quantities of purchased parts, and smaller number of spare components needed because of the interchangeability of components.

Table 3-4. Standardized Actuator Cost Savings

Type	Total Qty of Units	Qual * Reduction	Quantity Procurement	Reduced Spares	Reduced Design Costs
A	2	10K	.5K	8.0K	5K
B	7	30K	3.0K	30.0K	20K
C	12	30K	1.0K	8.5K	8K
Subtotal		70K	4.5K	46.5K	33K
Total			154K		

3.1.4 IMPACT OF TDRSS

Incorporation of a large pointable TDRSS antenna in lieu of the wideband system results in an overall cost and weight impact to the spacecraft structure and mechanisms in addition to the cost delineated in other subsystem areas.

The TDRSS installation on the Delta launch vehicle and the orbital spacecraft configuration are shown on Figure 3-15. The TDRSS antenna and boom are stowed above the instrument support structure which has been strengthened in the forward area to support the furlled antenna. The erectable boom is attached at the base and deployed by use of a rotary actuator. Overall boom height is nine feet for the eight foot diameter antenna shown.

Cost and weight increases over the baseline system result primarily from addition of the boom and erection mechanism and the need for a heavier two axis gimbal drive for the large antenna. Additional non-recurring costs are incurred for structural and mechanisms design plus additional systems level testing required to verify the erected antennas dynamic characteristics. Cost and weight deltas for the addition of TDRSS are:

Item	Non-Recurring	Recurring	Weight (lb)
Gimbal Drive	600-K	300-K	10
Boom, Deployment Mech. and Structure	150-K	75-K	50
Structure and Dynamic Tests	100-K	--	--
Total	750-K	375-K	60 lb

Antenna and associated equipment costs and weights are summarized in the wideband section.

3.1.5 IMPACT OF SOLAR ARRAY DESIGN

The baseline solar array for either configuration is a rigid folding array as illustrated on Figure 3-16. Either arrangement would use an identical type of array construction, similar deployment mechanisms, and total system array area and cost would be approximately equal.

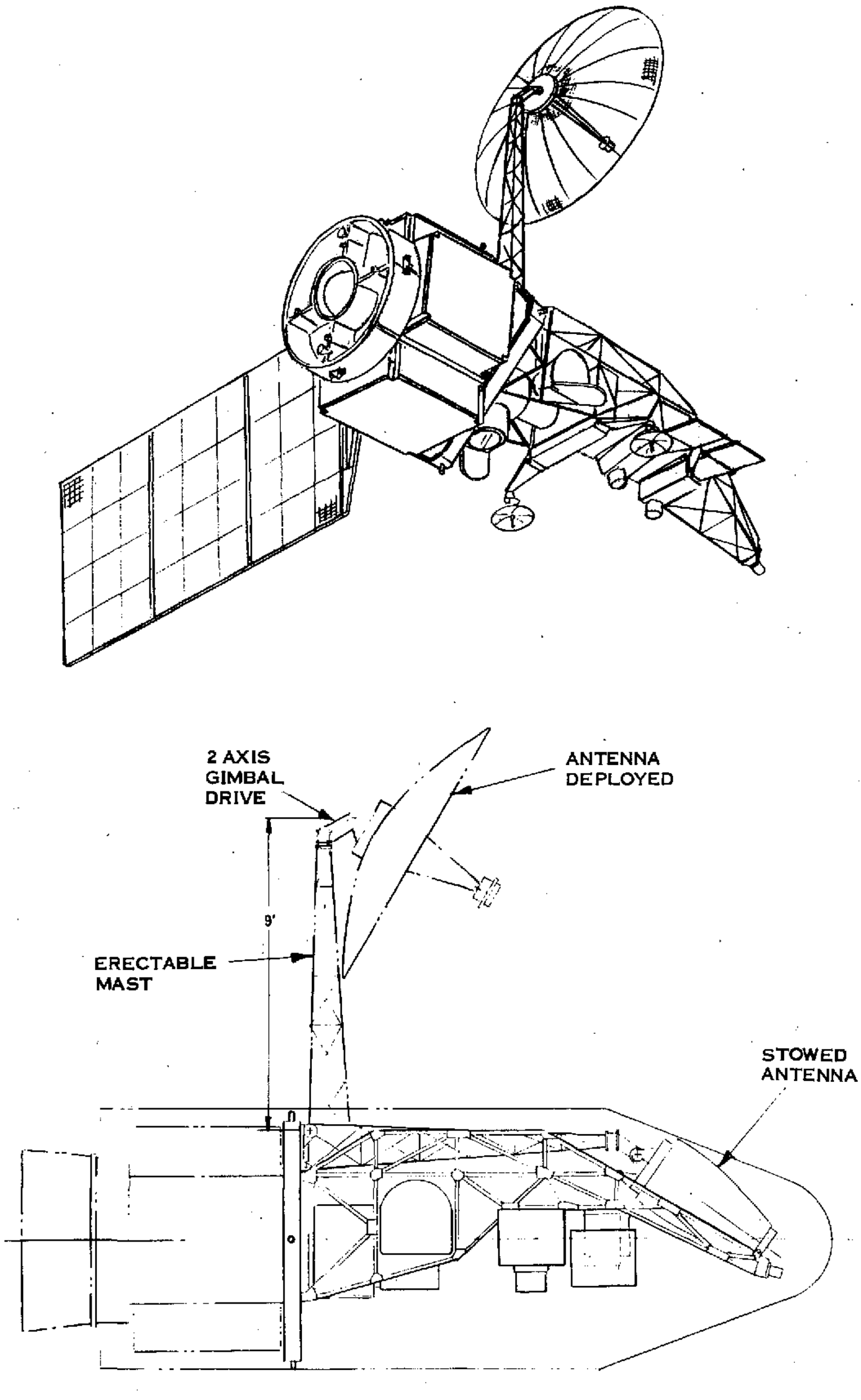
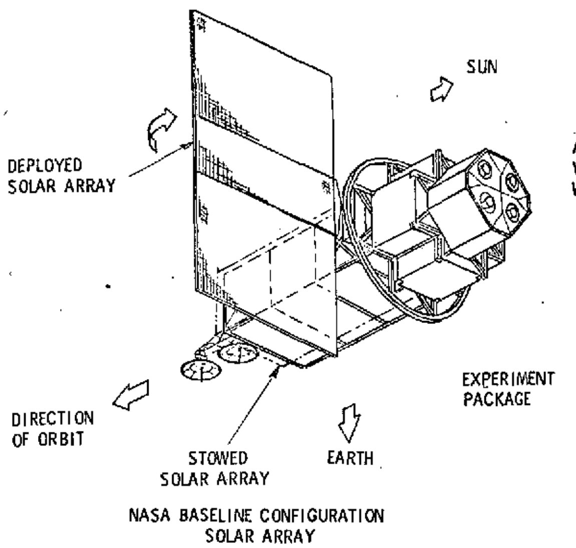


Figure 3-15. TDRSS Antenna Installation



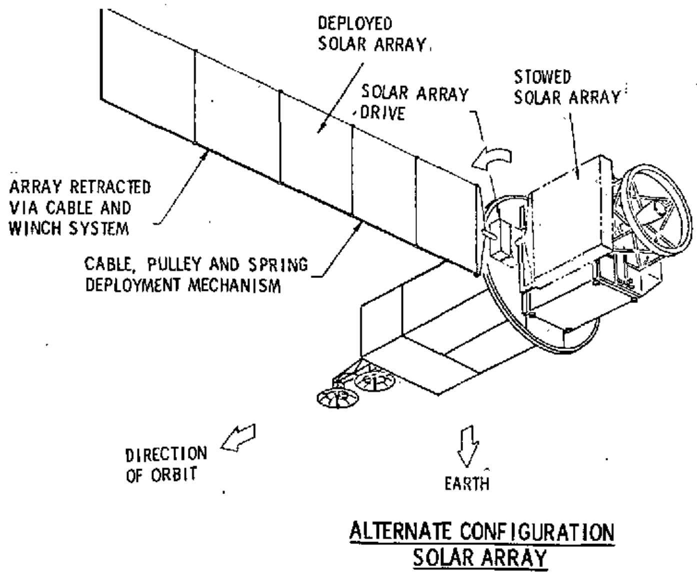


Figure 3-16. Rigid Solar Array Configurations

An alternate roll-up solar array could be used as shown on Figure 3-17. It allows additional configurational flexibility, but these advantages are more than offset by the approximately 25 percent higher cost over the rigid array approach (see Power Section).

3.1.6 IMPACT OF TM/HRPI APPROACH

The design studies for the three candidate Thematic Mappers, and three candidate scanning HRPI's and the one pushbroom array HRPI are all generated to slightly different baselines. The resulting sizes and weights vary significantly and are probably more representative of degree of design completeness than of basic differences between approaches. Theorically, the object plane scanner should be smaller and lighter. However, all were assumed to be equally compatible from a structural accommodation point of view.

Table 3-5 indicates the orientation of the candidate instruments to the spacecraft velocity vector. Earlier discussions (see Figures 3-1 and 3-2) show either orientation, or different

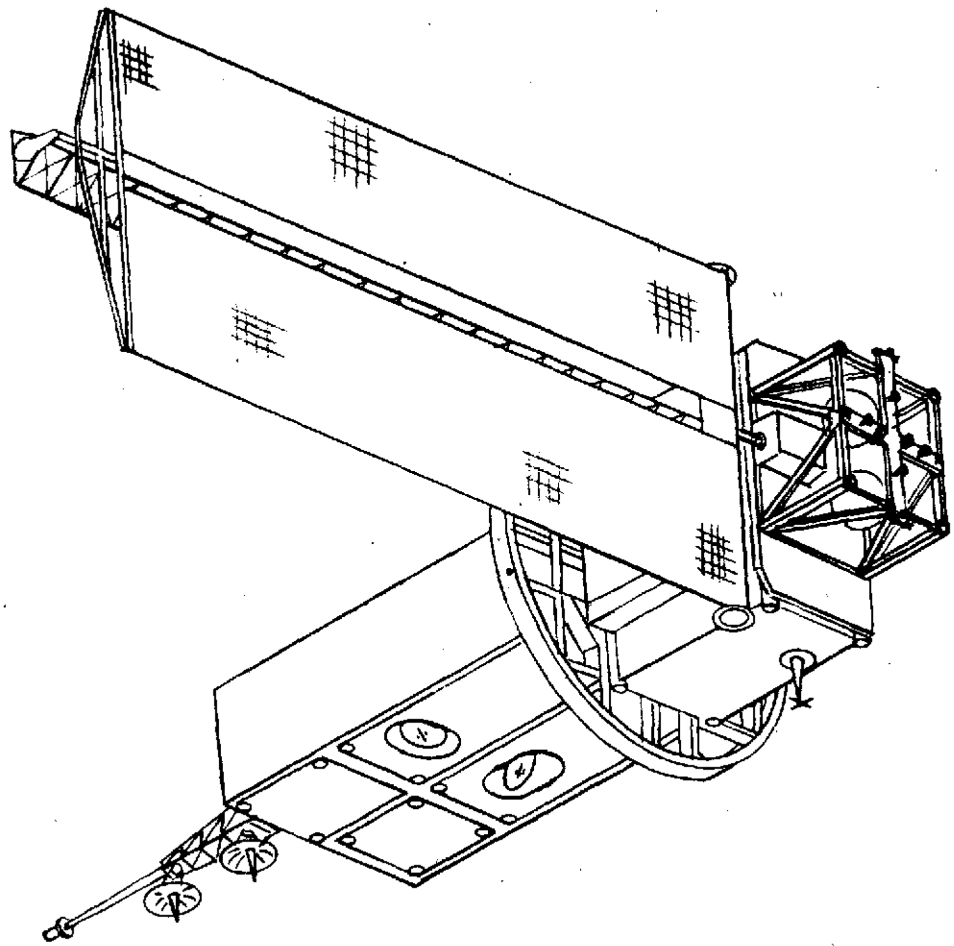


Figure 3-17. Alternate Roll-Up Array

orientations for each instrument, can be accommodated with little change to the basic design concept.

Table 3-5. Instrument Orientation with Respect to Velocity Vector

Type Of Scan	TM	HRPI
Image Plane Scanner	either	parallel
Object Plane Conical Scanner	either	parallel
Object Plane Linear Scanner	perpendicular	perpendicular
Pushbroom Array	--	perpendicular

The TM's require approximately $\pm$ 8 degree field of view toward nadir from the instrument's optical axis. The HRPI and ScHRPI's require a $\pm$ 48 degree clear field of view. These can be

C-2

accommodated by mounting the ScHRPI more earthward within its instrument module than the TM.

All candidate TM's require a radiant cooler for the thermal band detectors. In the point study reports, the contractors sized the coolers and oriented the fields of view for a 9:30 orbit. These designs will have to be reworked by the contractors for an 11:30 orbit, but no design accommodation problems are envisioned with the single solar array concept.

3.1.7 IMPACT OF SHUTTLE RETRIEVAL/RESUPPLY

The assessment of Shuttle Retrieval and Resupply impact in this section is limited to cost and weight effects on the spacecraft structure and mechanisms. Overall system cost analyses, effects on the Shuttle equipment weight and cost, and integrated Spacecraft/Shuttle and equipment verification test costs will be included in Report No. 6, "Space Shuttle Interfaces and Utilization."

Retrieval/Resupply Modes. Cost/weight penalties to the spacecraft structure and mechanisms have been estimated relative to an expendable (no retrieval or resupply) design. This expendable "reference" spacecraft would employ subsystem modularity and separate rigidly joined subsystem (BUS) and instrument sections to enhance producibility and development schedules, but would have no provisions for Shuttle launch, retrieval or resupply.

In the retrieval mode the spacecraft would be captured by the Shuttle and returned to earth for ground repair and relaunch. The retrieval model requires addition of a central transition ring or frame to interface with the Shuttle retention cradle. Launch and/or retrieval only will result in a simplified FSS providing spacecraft retention and erection capability only, and SAMS will be used for spacecraft deployment and capture. Retrieval capability is also included for all other resupply modes.

Subsystem (BUS) section and instrument section resupply would permit exchange of these sections at the transition frame. This mode requires design and development of remotely activated latches and electrical disconnects for the spacecraft and an exchange/storage capability for the FSS.

Module exchange capability using the FSS and SPMS equipment, as illustrated on Figure 3-18, requires a separable module for each subsystem and instrument. These modules will have corner latch fittings to interface with the SPMS and remote electrical disconnects. In addition provisions for exchange of appendages such as the solar array and antennas using SAMS are required. This mode makes maximum use of the Shuttle systems for on-orbit servicability, but results in the highest spacecraft weight and cost.

The module latch and connector mechanisms employed are shown in Figure 3-19 and represents an optimization of the GSFC baseline design to reduce weight and cost. The concept utilizes the basic NASA design of a module latch but absorbs load only at the conical seats, thus eliminating guide rails. A conical section at the latch base helps guide the module into position and then positions it to within 0.10" of true position to accommodate the electrical connector mating which can absorb up to 0.15" or misalignment. The module latch housing can be cut away in many places to provide a lightweight, yet sturdy, corner fitting.

The G&H Technology electrical connector shown has been qualified for aircraft use and is being studied as a prime candidate for the electrical connector.

Cost/Weight Impact. Effects of retrieval and resupply to the spacecraft cost and weight are listed in Table 3-6, and relative effects to the Shuttle systems are summarized. Costs shown include design, analysis and development test (NR, non-recurring) and hardware costs per spacecraft (R, recurring). Weights shown are additional weight over and above the reference (expendable) design. Note that retrieval costs and weights are included in the resupply mode totals shown.

This study indicates the baseline module resupply mode results in weight impact to the spacecraft which may be prohibitive for pre Shuttle launch vehicles. This mode, however, can potentially produce the maximum cost effectiveness for the overall system during the Shuttle era.

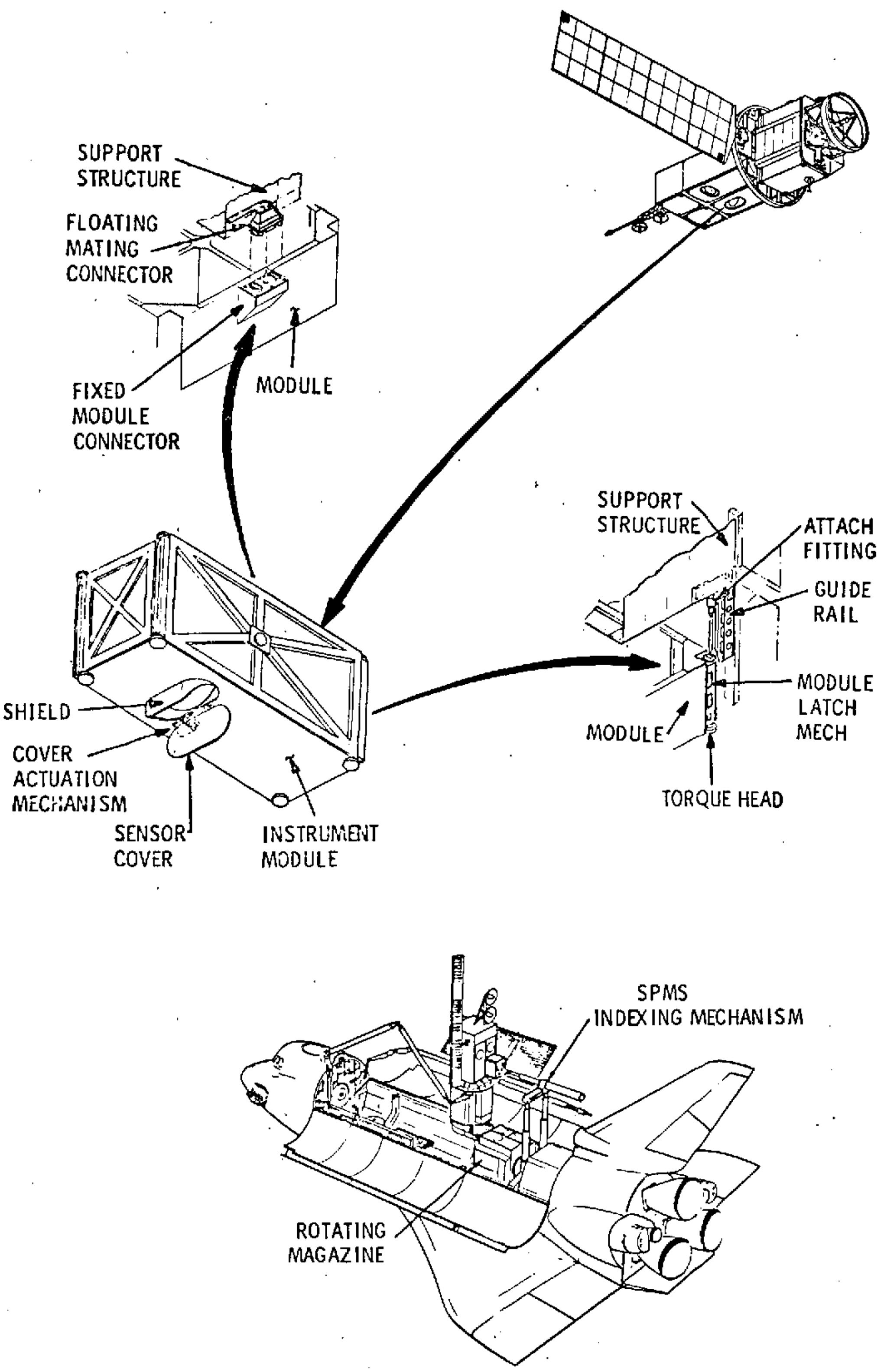


Figure 3-18. Module Exchange

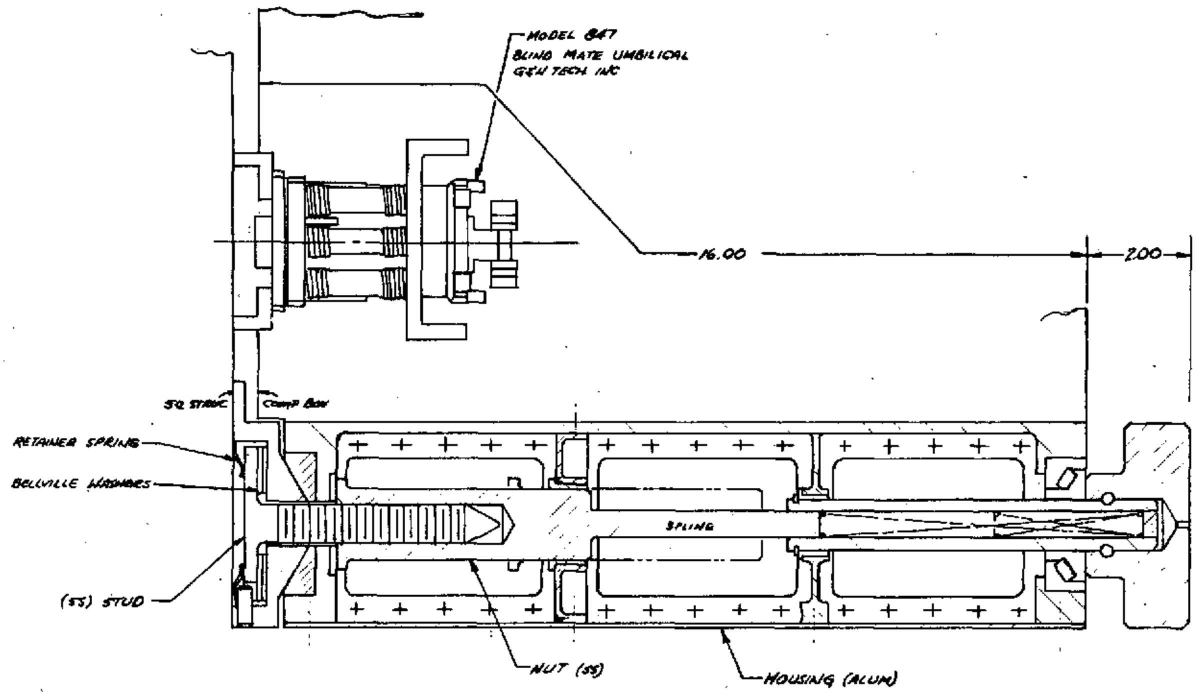


Figure 3-19. Optimized Module Latch Mechanism

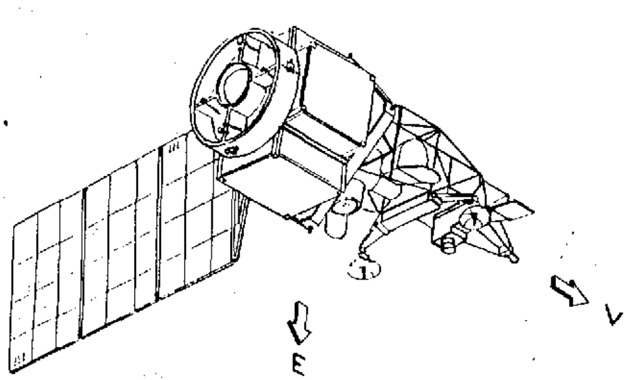
The retrieval and section resupply modes result in significantly lower cost and weight penalties to the spacecraft and may prove to be viable contenders for early EOS application. The section resupply mode, in particular, having capability for on-orbit exchange of either the BUS or instrument sections, may provide adequate resupply capability at lower cost and weight to the basic spacecraft.

3.1.8 FOLLOW-ON INSTRUMENT ACCOMMODATION

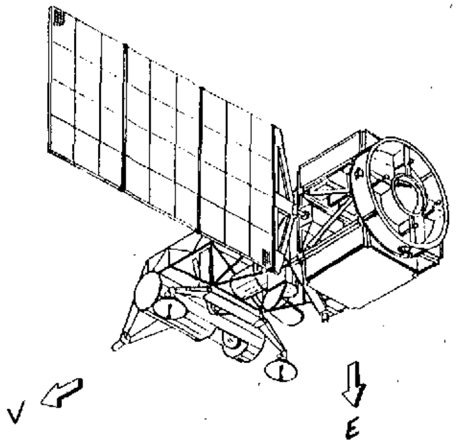
EOS orbital configurations for alternate payloads are shown on Figure 3-20. These modular configurations have a BUS section designed to interface with either Delta or Titan launch vehicles using a conventional adapter, and a central transition frame for attachment to the FSS for launch or retrieval by Shuttle. Instrument installations shown are fixed mountings not configured for resupply. Resupply provision will require individual modules for each instrument plus addition of corner latches on the subsystem modules.

Table 3-6. EOS Retrieval/Resupply Mechanical Design Impact

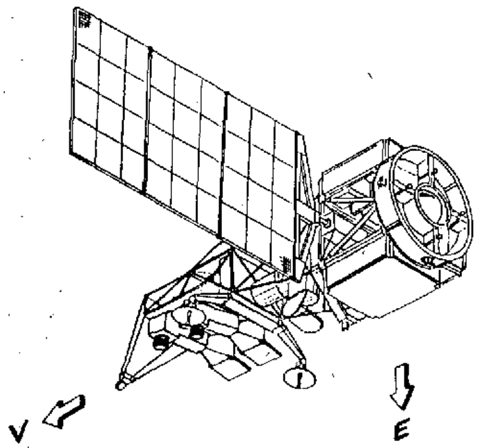
Mode	S/C Mechanical Impact				Shuttle Equipment	Conclusions
		Cost				
	Configuration	NR	R	Weight		
Expendable Spacecraft (no retrieval or resupply)	• Fixed S/S modules • Built-in instrument mts.	-0-	-0-	-0-	Not compatible with Shuttle launch	• Lowest weight spacecraft • Requires complete S/C replacement to correct any failure on orbit • Max schedule impact • Potentially highest cost to system
Retrieve (no resupply)	• Fixed S/S modules • Built in instrument mts. • Transition frame • S/S & instrument sections rigidly joined at frame	185K	37K	150 lb	• Simplified FSS (retention & erection only) • SAMS for S/C development & capture	• Retrieve for either S/S or instrument failure • Ground repair • Simplified Shuttle interraces & equipment • Long repair & replacement schedule • Lowest weight S/C for re-use
S/S (BUS) and Instrument Sections Resupply (& S/C retrieval)	• Fixed S/S modules • Built in instrument mts • Transition frame • S/S & instrument sections removable at transition frame	395K	69K	255 lb	• FSS modified to incorporate section exchange mechanisms (horizontal exchange) • 2 SAMS for handling sections • Storage fixtures	• BUS or instrument section exchange on Shuttle • Requires simplified exchange mechanism • Maximum shuttle payload sharing • Moderate schedule impact • Most adequate for major S/S instruments changes
Module Resupply (& S/C Retrieval) Baseline	• Removable S/S and instrument modules with remote latches & elect. disconnects • Transition frame • S/S & instrument sections Rigidly joined at frame • Replaceable appendages	623K	168K	570 lb	• FSS including S/C indexing capability • SPMS for module exchange • SAMS for appendage exchange • Storage provisions for modules in SPMS magazine & fixtures for appendages	• Exchange failed S/S module or instrument • Most complex & heaviest spacecraft • Requires most complex exchange mechanisms & has highest weight & volume to Shuttle • Shortest schedule impact • Maximum utilization of Shuttle • Potentially most cost effective



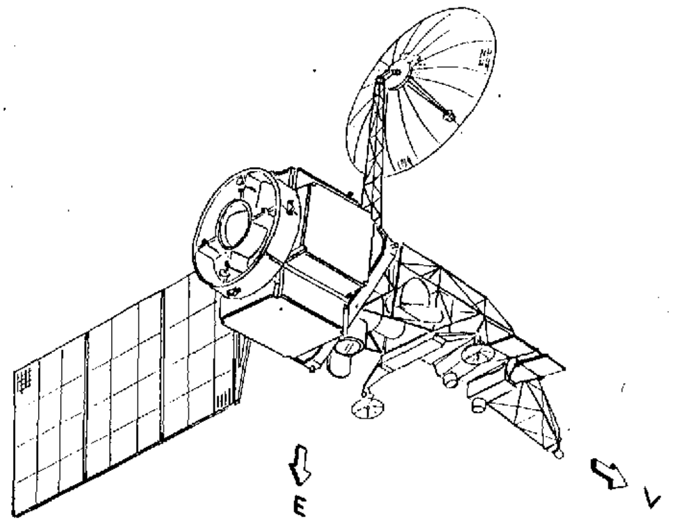
EOS - TM + MSS



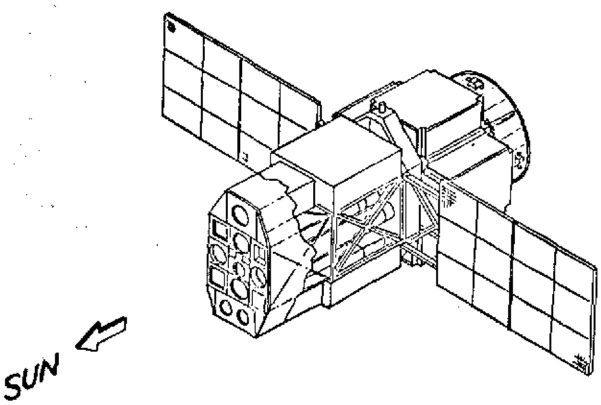
EOS - TM + HRPI



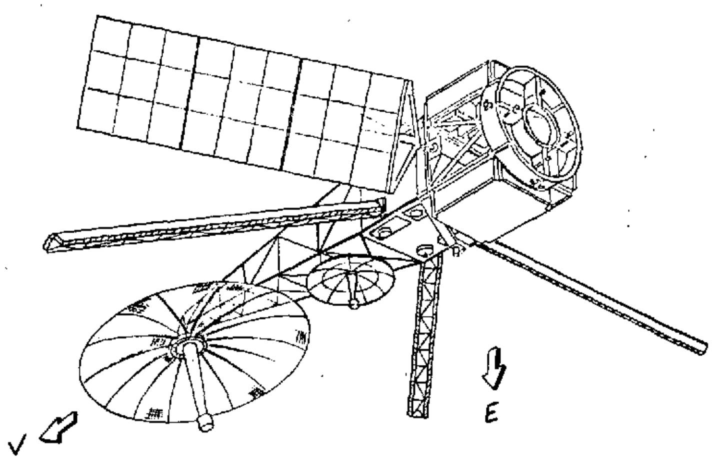
EOS - TM + DUAL MSS



EOS - TM + DUAL MSS WITH TDRSS



EOS - SOLAR MAXIMUM



EOS - SEASAT

Figure 3-20. EOS Alternate Mission Configurations

Payloads illustrated are:

- Thermatic Mapper plus 5-Band MSS - Single Axis Oriented Solar Array
- Thermatic Mapper plus HRPI - Single Axis Oriented Solar Array
- Thermatic Mapper plus Dual 5-Band MSS - Single Axis Oriented Solar Array
- TM + Dual MSS Including TDRSS gimballed antenna
- Solar Maximum Payload - Fixed Solar Array
- Seasat Multi-Sensor Payload - Dual Axis Oriented Solar Array

These arrangements show the flexibility of the BUS concept to accept a wide variety of sensors with little change to the basic spacecraft design.

3.2 THERMAL CONTROL DESIGN/COST TRADEOFFS

Four basic cost trade-off questions were addressed, namely:

1. What should the temperature control range be ?
2. What type(s) of control should be used ?
3. Is standardization of implementation (i. e., standard control elements or materials) for all spacecraft modules cost effective ?
4. Does the design postulated readily adapt to other mission requirements ?

The first three were addressed in combination after the basic cost data was derived.

3.2.1 SIZING REQUIREMENTS AND ASSUMPTIONS

The generic thermal control requirements are presented in Table 3-7. Nominal values of the radiation parameters were used in all design trade-offs. The mission parameters influencing the thermal design for EOS-A and other projected missions are presented in Table 3-8. The cost criteria used for evaluating various thermal control equipment and materials is given in Table 3-9. Properties and cost of thermal coatings evaluated are shown in Table 3-10.

3.2.2 PERFORMANCE/COST ANALYSIS

As a preliminary step in the cost/performance analyses, verification of the heat rejection capability of the various modules sizes, in their various locations (for the triangular and rectangular configurations) was conducted to show that adequate heat rejection margin exists without constraining the sizing or location of modules because of thermal constraints. The nominal dissipations of Table 3-11 were used. No constraints were found. The minimum dissipation margin was 40 percent for the worst combination of module size/locations examined.

Table 3-7. Generic Thermal Control Requirements

Parameter	Requirement
o Launch Vehicle	Delta, Titan or Space Shuttle Compatibility
o Configuration	
Subsystem Modules	Independent thermal control for any configuration or mission
Instrument Modules	Independent thermal control with mission peculiar configuration
o Temperature Control Range	$70^{o}F \pm TBD$
o Radiation Parameters	
Solar Constant	429.0 BTU/hr. ft^2 + 4.3 BTU/hr. ft^2 with +3.43%, -3.26% seasonal variation
Albedo	0.30 $^{+0.30}_{-0.15}$
Earth IR	75.1 BTU/hr. ft^2 +8.9 BTU/hr. ft^2 -30.8 BTU/hr. ft^2

Table 3-8. Multi-Mission Environment Parameters

Mission	EOS A	EOS B	EOS C	Shuttle Resupply	SEOS	Solar Max.	Seasat A/B	5 Band MSS
Altitude, nm	420	450	418	300	19,323	285	430/324	500
Attitude	← 3 axis control →							
Orientation	Earth	Earth	Earth	Earth	Earth	Sun	Earth	Earth
Inclination	99^{o} Sun Syn.	99^{o} Sun Syn.	99^{o} Sun Syn.	28.5^{o}	Geo	30^{o}	$108/90^{o}$	99^{o} Sun Syn.
Asc Node Time	2330	1200	2330	---	---	N/A	N/A	2330/0930
Life Time	2 yrs.	2 yrs.	2 yrs.	7 days	2 yrs.	1 yr.	5 yr.	1 yr.
Beta Angle Variation, degrees	7.5 $\pm 5.^{o}$	7.5 $\pm 5^{o}$	7.5 ± 5		0^{o} $\pm 23.5^{o}$	N/A	0^{o} $\pm 90^{o}$	7.5 ± 5^{o} 37.5 ±8

Table 3-9. Cost of Thermal Control Hardware

Cost Trade Area	Non-recurring	Recurring Cost	Weight	Comments
Multilayer insulation		$ 11.0/ft^2	0.10 lb/ft^2	20 layers 1/4 mil mylar aluminum both sides & 19 layers of acron mesh in between
Mechanical Thermostats		$300/assy	0.09 lb/assy	includes one nominal, one high cut off and one low turn on for redundancy.
Electric Thermostats		$600/assy	0.6 lb/assy	includes sensor and assembly redundancy
Louvers	$9500/ft^2	$2100/assy $3000/assy	2.4 lb/assy 0.9 lb/assy	fluid activated louver bi-metallic activated lower
Compensation Heaters		$225/heater	0.8 lb/watt	includes installation cost
Heat Pipe	$120K 1st module	$43K/module	0.2 lb/ft (16 lb/module)	
Intermediate	$17K/module	$5100/module	7.7 lb/module	

Table 3-10. Thermal Control Coating Performance Data

	Beginning of Life	Optical Properties 1 Yr.	2 Yr.	5 Yr.	Specific Weight lb/ft^2	Specific Cost \$/ft^2
OSR (Optical Solar Reflector)	.06/.76	.08/.76	.10/.76	.16/.76	.095	1150.
S-13G White Paint	.21/.87	.33/.87	.38/.87	.42/.87	.080	25.
5 mil Teflon over Silver	.09/.83	.12/.83	.15/.83	.22/.83	.060	30.
Alzak	.14/.75	.24/.75	.32/.75	.40/.75	.030	10.
Chemglaze Z 306 (Black)	.92/.96	.92/.96	.92/.96	.92/.96	.030	10.

Table 3-11. Module Orbit Average Dissipations

Module	Dissipation (watts)		
	Max.	Nom	Min.
ACS	105.6	96.0	86.4
C&DH	153.7	139.7	125.7
Power	113.5	103.2	92.9

Passive Thermal Control. The next step in the analysis was to consider in detail a passive thermal control approach for the recommended spacecraft configuration (rectangular arrangement of modules). For the EOS-A orbit, the average heat rejection capability as a function of radiator surface temperature for each subsystem module for five candidate heat rejection coatings (Table 3-10) was developed. An example for the C&DH module is shown in Figure 3-21. Degradation corresponding to a 1-year mission were used. The black (high α/high ϵ) coating is included because it is inexpensive and does not degrade significantly with life. Table 3-12 shows the cost for the various thermal coatings to maintain a specified 70 $\pm$ TBD ^{o}F temperature range, along with the cost model. The maximum and minimum orbit average dissipations from Table 3-11 were used along with the coating initial and degraded values shown in Table 3-10 for the definition of heat rejection area and minimum average power required. The minimum average power required can consist of electrical power dissipation and heaters. When the

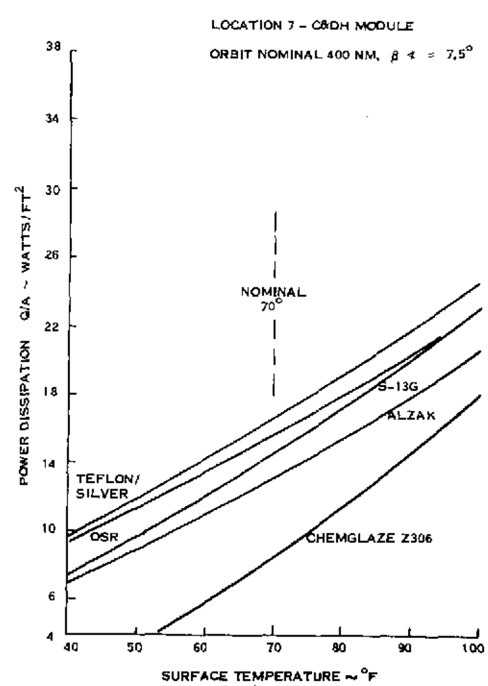


Figure 3-21. Power Dissipation vs. Surface Temperature

required power is less than the maximum average dissipation but greater than the minimum, compensation power is required with compensation heaters.

If the required power is greater than the maximum dissipation, solar array power is required with the associated cost penalty. The area required is based on maximum average orbit power dissipation and degraded coating properties (1 year) while the minimum average power is based on initial coating properties. For the power module which contains batteries with 32° to 68°F temperature level requirement as well as electrical equipment, the nominal temperature was set at 50°F for the tradeoff. As long as adequate heat rejection area exists, biasing the average module temperature to a slightly lower value is more cost effective than alternate designs using either more complex thermal control schemes or double radiators which would result in two types of module designs per vehicle.

The results of the cost trade presented on Table 3-12 show:

1. Chemglaze does not provide adequate heat rejection for the ACS module size or for the smaller C&DH module.

2. The minimum cost thermal control for each temperature range using any coating is:

Total Cost	Temp. Range
\$ 510	$\pm 20^{\circ}$F
3000	± 10
5670	± 5

3. Teflon/silver provides the most cost effective approach if only one coating is used (except at the $\pm 20^{\circ}$F range). Its cost would be:

Total Cost	Temp. Range
\$ 800	$\pm 20^{\circ}$F
5300	± 10
8490	± 5

4. Passive thermal control costs are small.

Table 3-12. Coating/Temperature Range Cost Trade-off - Passive Design

Module	Orbit Avg Dissipation (Watts) Max./Min.	Temperature Range (°F)	Thermal Coating: 5 mil Teflon/Silver Area (ft²)	Min Pwr Req'd (Watts)	Comp. Heater Pwr Req'd (Watts)	Array Pwr Req'd (Watts)	Cost K $	OSR Area (ft²)	Min Pwr Req'd (Watts)	Comp. Pwr Req'd (Watts)	Array Pwr Req'd (Watts)	Cost K $	S-13G Area (ft²)	Min Pwr Req'd (Watts)	Comp. Pwr Req'd (Watts)	Array Pwr Req'd (Watts)	Cost K $	Alzak Area (ft²)	Min Pwr Req'd (watts)	Comp. Pwr Req'd (watts)	Array Pwr Req'd (watts)	Cost K $	Chemglaze Z306 Area (ft²)	Min Pwr Req'd (watts)	Comp. Pwr Req'd (watts)	Array Pwr Req'd (watts)	Cost K $
ACS	105.6/86.4	70 ± 20	3.17	78.0	0	0	0.24	3.33	77.4	0	0	3.97	3.94	83.4	0	0	0.23	4.26	84.7	0	0	0.17					
		70 ± 10	3.45	196.7	10.3	0	2.79	3.62	92.3	5.9	0	6.85	4.42	104.1	17.7	0	2.67	4.71	103.3	16.9	0	2.72					
		70 ± 5	3.60	101.0	13.6	0	2.79	3.77	100.2	13.8	0	7.02	4.67	115.8	19.2	10.2	13.0	4.98	114.6	19.2	9.0	11.7					
C&DH	153.7/125.7	70 ± 20	7.05	86.49	0	0	0.31	7.53	86.93	0	0	8.75	7.69	86.64	0	0	0.28	8.59	88.26	0	0	0.17	10.53	30.63	0	0	0.17
		70 ± 10	8.05	117.05	0	0	0.33	8.59	117.0	0	0	9.96	8.94	122.0	0	0	0.30	9.92	122.3	0	0	0.17	13.47	74.61	0	0	0.16
		70 ± 5	8.63	135.74	10.0	0	2.89	9.20	135.37	9.7	0	13.21	9.73	144.9	19.2	0	2.86	10.75	144.1	18.4	0	2.72	15.37	106.2	0	0	0.16
Power	113.5/92.9	50 ± 20	4.00	78.55	0	0	0.25	4.35	78.48	0	0	5.13	3.89	78.85	0	0	0.23	4.49	78.97	0	0	0.17	3.70	75.90	0	0	0.17
		50 ± 10	4.37	94.63	1.7	0	2.81	4.75	94.47	1.6	0	8.14	4.25	95.13	2.2	0	2.79	4.89	94.91	2.0	0	2.72	4.05	92.53	0	0	0.17
		50 ± 5	4.58	104.0	11.1	0	2.81	4.98	103.90	11.0	0	8.40	4.45	104.57	11.7	0	2.79	5.14	104.70	11.8	0	2.72	4.27	102.81	9.9	0	2.72

Cost Model:

Cost = |Number of heaters/module| |Cost/heater| + |min. pwr req'd - max. orbit avg. Diss.| |Array cost/watt| + |Area req'd| |Coating cost/ft²|
+ |Module area - area req'd| |insulation cost/ft²| + |number of thermostats| |cost/thermostat|

(1) If module need comp or array power, number heaters = 10, and number thermostat groups = 1
(2) Cost/heater = $225
(3) Array cost/watt = $1000, at low altitude and $500 at geosynchronous
(4) Coating cost/ft² from Table 3-10
(5) Insulation cost/ft² = $11.0
(6) Module area = 16 ft²
(7) Cost/thermostat = $300

Alternate Thermal Control Concepts. Three alternate thermal control concepts were also evaluated for their cost effectiveness. None were selected for the reasons shown in Table 3-13.

Table 3-13. Cost of Alternate Thermal Control Concepts

Concept	Cost	Remarks
Intermediate Radiators	\$6.1K/module	Assumes all modules use concept. Excludes coatings, heaters, etc.
Louvers	4 times passive	
Heat Pipes	\$50 to 63K/module	Excludes coatings, heaters, etc.

Temperature Control Range. System cost savings can be realized if incresing the nominal cost of the base thermal control system can be offset by other system cost reductions, such as piece part selection, number of failures and failure reports, design simplifications, and test cost reductions. The potential impact of these cost reductions was assessed considering only test savings. From actual data, Nimbus/ERTS ACS module thermal vacuum tests cost \$2969/day including labor and facilities. If narrowing the temperature control range to $\pm 5^{\circ}F$ saved two days of testing (since the temperature plateau cycling could be reduced), the break-even point would be reached. This cost saving would be significantly increased if more than two days of testing could be eliminated or when other considerations such piece part selection, failure, re-tests for failure, and failure reports are included. Therefore, reducing the temperature control range is cost effective, and a $\pm 5^{\circ}F$ baseline temperature control range is selected with a $70^{\circ}F$ nominal temperature for the ACS and C&DH modules and $50^{\circ}F$ nominal temperature for the battery module.

Alternate Missions. In order to evaluate the effect of alternate missions on the baseline design, each mission was analyzed considering the parameters of Table 3-8. The results are presented in Table 3-14 and discussed below:

1. EOS B and C. The EOS-B and C missions are essentially the same as EOS-A even though there is a slight variation in altitude.

2. Shuttle Resupply. The Shuttle resupply varies in orbit inclination, altitude, and duration from EOS-A. There is no change in the propulsion or ACS module designs and only slight heat rejection/compensation heater requirement changes for the Power and C& DH modules. The Shuttle resupply mission provides no cost impact.

3. Solar Maximum. The Solar Maximum mission is sun oriented and the module surfaces receive no solar and minimal albedo flux. The EOS-A coatings would result in too low temperatures for the propulsion module, and costly subsystem module designs caused by the need to utilize array power (due to the variation in the heat rejection coating optical properties). Using a propulsion module coating with high α/ϵ's such as Aluminized Kapton with ($\alpha/\epsilon = .16/.04 = 4.0$) on the end and gold coated ($\alpha/\epsilon = .30/.03 = 10.$) on the circumference, a comparable cost approach results in adequate propulsion module temperature control. For the subsystem modules, changing the heat rejection coating from 5 mil Teflon over silver to Chemglaze Z306 black paint (which does not significantly degrade) results in cost reductions to those comparable with the EOS-A baseline costs.

4. SEASAT A/B. SEASAT A/B differs significantly from EOS-A in that the sun angle will vary throughout the mission $0^{\circ} \pm 90^{\circ}$, resulting in a wide range of sinks for all equipments. The propulsion module requirements can be met using a properly balanced coating which maintains an adequate average orbit temperature for all Beta angles. The subsystem module control requirements required further cost evaluation as shownin Table 3-14. The baseline coating system resulted in a comparable cost for the C& DH module with costs increased about a factor of three for the ACS Module and 50 for the Power Module. The wide sink variations coupled with close temperature control resulted in a requirement for array power, causing the cost increase. Using OSR, a much costlier coating requiring no array power for the ACS module and less for the power module resulted in a 24% reduction in the ACS module cost and 44% reduction in power module cost. However, the power module cost is still 29 times higher than the baseline. A louver system was shown to be about the same cost as the baseline for the ACS module with negative heat rejection capability (not feasible) for the power module. The nominal cost of a heat pipe system at 120K for one module and 81.8K each for two modules is not cost effective. For comparative purposes the cost decrease available by increasing the temperature control range from $\pm 5^{\circ}F$ to $\pm 20^{\circ}F$ was evaluated as shown for both the 5 mil Teflon/Silver and OSR coatings. However, the reduction in test cost would offset this cost reduction. Therefore, the most cost effective system is passive with OSR for both the ACS and power module.

Table 3-14. Alternate Mission Comparison

Module	Parameter	EOS-A	EOS B&C	Shuttle Re-supply	Solar Max.		SeaSat A/B					5 Band MSS	SEOS					
ACS		①	①	①	①	②	①	③	④	⑥	⑦	①	①	③	④	⑤	⑥	⑦
	Area, ft^2	3.60	3.60	3.60	3.82	3.65	3.60	3.76	5.4	3.17	3.33	3.60/3.50	5.50	4.98	∞	1.87/side	4.58	4.2
	Min. Pwr Req'd-watts	101.0	101.0	101.0	119.6	95.1	111.9	100.0	90.4	87.6	84.7	101./100.6	175.5	144.4		25.0	129.1	108.4
	Comp. Heater Pwr-watts	13.6	13.6	13.6	21.2	8.7	19.2	13.6	0.0	1.2	0.0	14.6/14.6	19.2	19.2		0.0	19.6	19.2
	Array Pwr Req'd-watts	0.0	0.0	0.0	14.0	0.0	6.3	0.0	0.0	0.0	0.0	0 /0	69.9	38.8		0.0	23.5	2.8
	Cost, K $	2.79	2.79	2.79	16.8	2.72	9.09	6.89	8.68	2.79	4.0	2.79/2.79	37.9	25.8		120.+	14.6	8.9
C&DH																		
	Area, ft^2	8.63	8.31	9.0	5.56	5.28	9.0			7.29	4.54	8.3/8.3	8.0	7.25	∞		6.67	6.12
	Min. Pwr Req'd-watts	135.74	136.6	143.2	174.1	138.6	143.2			87.8	50.8	136.4/136.6	253.2	210.0			188.0	159.6
	Comp. Heater Pwr-watts	10.0	10.9	17.5	28.0	12.9	10.5			0.0	0.0	10.7/10.9	26.0	26.0			26.0	26.0
	Array Pwr Req'd-watts	0.0	0.0	0.0	20.4	0.0	0.0			0.0	10.0	0.0/0.0	99.5	56.3			35.3	5.9
	Cost, K $	2.89	2.88	2.90	23.2	2.72	2.90			0.31	5.35	2.88/2.88	52.7	39.5			20.5	2.95
Power																		
	Area, ft^2	4.58	4.48	4.64	4.64	4.43	11.87	9.08	∞	8.65	7.20	4.48/4.48	4.87	4.97	8.1		4.23	4.35
	Min. Pwr Req'd-watts	104.0	103.8	102.7	102.7	108.2	256.6	186.0		166.8	727.1	103.8/108.0	131.9	123.3	26.4		101.5	95.7
	Comp. Heater Pwr-watts	11.1	10.9	9.8	9.8	9.3	10.6	10.6		1.8	9.8	10.9/11.1	10.6	10.6	0		8.6	2.8
	Array Pwr Req'd-watts	0.0	0.0	0.0	0.0	0.0	143.1	72.5		53.3	13.6	0 /0	18.4	9.8	0		0.0	0.0
	Cost, K $	2.81	2.81	2.81	2.81	2.72	145.8	81.2		56.2	24.5	2.81/2.81	12.0	13.3	12.9		2.51	7.68

① 5mil Teflon/Silver
② Change to Chemglaze Z-306
③ Change to OSR
④ Change to Louvers
⑤ Change to heat pipes with insulated top and sides open-heat pipes controllable
⑥ Control range increased to ± 20°F
⑦ Control range increased to ± 20°F and change to OSR coating.

5. 5-Band MSS. The 5-Band MSS mission differs slightly in altitude with a range of anticipated sun synchronous orbits. The analysis indicates no changes in requirements from the EOS-A baseline are required and there are no cost affects.

6. SEOS. The SEOS mission is significantly different from the EOS-A baseline in that the geosynchronous orbit with a 24-hour period results in long periods of solar illumination followed by long periods with no external heat inputs on each vehicle surface. Solar illumination varies both with time of day and season . In addition, the orbital thermal control control concept must be augmented, if required, to protect vehicle equipments during the long transfer orbit. The baseline coatings will cause costs to increase by a factor of 12. This increase is not as costly as for the Seasat mission since array power is cheaper at synchronous orbit. These costs can be reduced 23% by utilizing an OSR coating. Using louvers is not feasible for the ACS and C&DH modules and provides no cost advantage for the power module. A heat pipe system (controllable) utilizing module side areas with insulated top surfaces is nominally too costly. Increasing the temperature control frange from $\pm 5^{o}F$ to $\pm 20^{o}F$ using either coating system does not appear attractive when test reduction costs are included.

The following general summary of comments appears applicable to alternate missions:

1. For earth oriented vehicles in low orbits variations in Beta angle, (sun synchronous) attitude, and inclination have no cost effects on the basic EOS-A design.

2. For vehicles with varying environments caused either by continued variation of Beta angle or synchronous orbit, a brute force passive thermal control approach using coatings, insulation, and array power as necessary is more cost effective than using more complex thermal control concepts.

3.2.3 CONCLUSIONS

The foregoing analysis leads to the following conclusions for the four basic thermal tradeoffs evaluated:

1. The temperature control range should $\pm 5^{o}F$.

2. Passive control (with heaters) should be used.

3. Some standarization of control coatings may be desirable, but is not essential nor does it have much cost impact.

4. Follow-on missions can be accomplished by passive techniques through selection of coating materials.

3.3 PROPULSION SUBSYSTEM DESIGN/COST TRADEOFFS

For the purpose of this study, the EOS propulsion subsystem is defined as a system having the combined capability of performing the spacecraft functions of reaction control, orbit adjust and orbit transfer. All design and cost trades are performed at this combined subsystem level thereby negating the necessity for arbitrary allocation at the functional level during evaluation of the alternate propulsion design concepts.

3.3.1 SIZING REQUIREMENTS AND ASSUMPTIONS

The propulsion subsystem provides the spacecraft propulsive functions required for reaction control, orbit adjust and orbit transfer. Two propulsion subsystem sizes have been analyzed to consider both the original and revised mission definitions:

1. A system compatible with a 4,000 pound spacecraft injected by a Titan IIIB launch vehicle, and
2. A system compatible with a 2,200 pound spacecraft injected by either a Delta 2910 or 3910 launch vehicle.

The EOS-A mission and spacecraft parameters contained in Table 3-15 were used to derive the requirements for the propulsion subsystem functions contained in Table 3-16.

3.3.2 CANDIDATE DESIGNS

The NASA/GSFC baseline design and two alternate propulsion subsystem designs were considered for the Titan class spacecraft. Two designs were evaluated for Delta launched spacecraft.

NASA Baseline - Titan. The NASA baseline propulsion system utilizes a pneumatics subsystem for accomplishing the functions of reaction control, a hydrazine system for orbit adjust and solid rocket motors for orbit transfer. The NASA baseline design block diagram, weight summary and thruster orientation details are defined in Table 3-17. Optimization of the NASA baseline includes the following:

Table 3-15. Mission and Spacecraft Parameters

• Mission Orbit	418 nm Circular	
• Retrieval Orbit	Circular at 300 nm Max.	
• Mission Lifetime	3 Years	
• No Single Point Failure Shall Prevent Shuttle Retrieval		
• Launch Vehicle	Titan IIIB Series	Delta Series
• Injection Orbit	100 x 418 nm Elliptical	418 nm Circ.
• Spacecraft Weight	4,000 lbs + Propulsion	2,200 lbs + Propulsion

Table 3-16. Propulsion Subsystem Requirements

	Titan Launch	Delta Launch
• Reaction Control Functions		
Initial Stabilization & Restab.	400 lb-sec	400 lb-sec
Backup Momentum Unloading	4550 lb-sec	2275 lb-sec
• Orbit Adjust Functions		
Inject. Error Removal - In Plane	20 fps	42 fps
- Cross Track	42 fps	16.5 fps
Orbit Maintenance	1.5 fps/Yr.	1.4 fps/Yr.
• Orbit Transfer Functions		
Mission Orbit Establishment	531.6 fps	Not Req'd
Retrieval - 300 nm Circ.	190.7/192.2 fps	190.7/192.2 fps
- 250 nm Circ. (Alternate)	273.8/276.9 fps	273.8/276.9 fps
S/C Control	100% Duty Cycle for One Engine	100% Duty Cycle for One Engine
Velocity Trim	1 1/2% of SRM Total Impulse	Not Req'd

Table 3-17. NASA Baseline Design - Titan

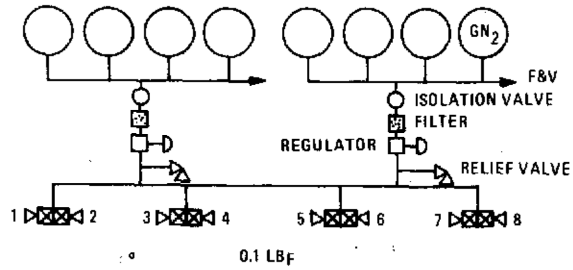
SUBSYSTEM WEIGHT

Reaction Control		231.0
Tankage	126.4	
Thrusters	5.6	
Other Hardware	20.7	
Gaseous Netrogen	78.3	
Orbit Adjust		173.5
Tankage	31.2	
Thrusters	32.0	
Other Hardware	14.4	
Hydrazine	92.5	
Pressurant	3.4	
Orbit Transfer		656.0
Motor 1	169	
Motor 2	166	
Motor 3	162	
Motor 4	159	
TOTAL		1060.5 lbs

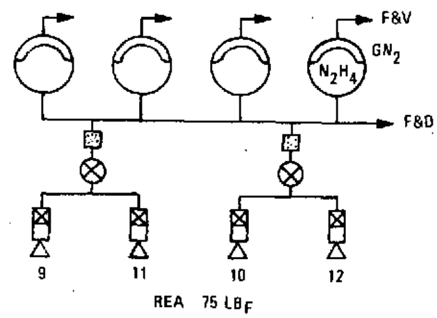
PROPELLANT BUDGET

Initial Stabilization	5.8
Momentum Unloading	66.5
Residual & Leakage	6.0
TOTAL	78.3 lbs.
Inject. Error Removal	38.4
Orbit Maintenance	21.0
S/C Control (SRM Burn)	20.9
Velocity Trim	10.0
3 δ Perf & Residuals	2.2
TOTAL	92.5 lbs

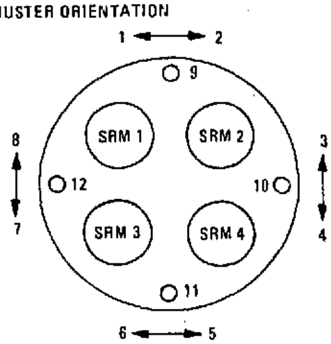
REACTION CONTROL



ORBIT ADJUST

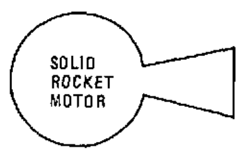


THRUSTER ORIENTATION



Motor No.	Δ V Req'd	Prop. Wt.	Motor Wt.
1	265	142	169
2	266.6	139	166
3	273.8	135	162
4	276.9	132	159
TOTAL		548 lbs	656 lbs

ORBIT TRANSFER



1. Reaction Control. The eight high thrust jets (operating at 1.0 pound force) were deleted since they have no functional utility for the EOS missions. Also, additional components such as isolation valves, filters and relief valves were added between the pneumatic tankage and the jets in order to further define a typical pneumatic propulsion system.

2. Orbit Adjust. The quad redundant check valves were replaced by latching valves and propellant line filters were added to make the system more representative of current hydrazine system designs. The system was reconfigured by deleting two of the four propellant feed circuits and combining the yaw REA's and pitch REA's on the remaining two circuits. Additionally the dual seat valves on the REA's were replaced by single seat valves in order to achieve improved predictability of engine pulse mode operation and to reduce system costs.

3. Orbit Transfer. The four Solid Rocket Motors (SRM's) were sized such that they would all contain approximately equal weights of propellant. The driving SRM sizing requirement is the establishment of the mission orbit from the launch vehicle injection orbit. Once these SRM's were sized, a circular retrieval orbit altitude of 250 nm was selected rather than the baseline retrieval altitude of 300 nm circular.

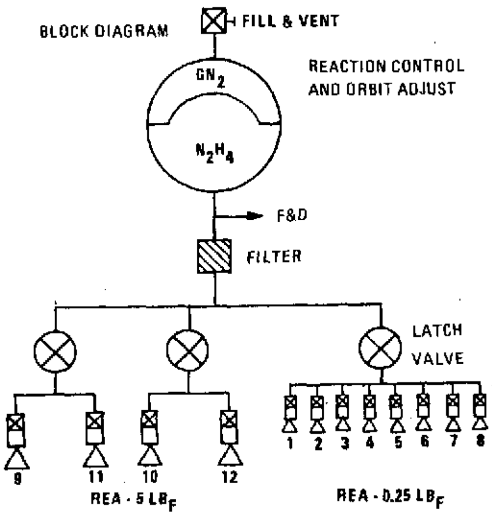
Alternate No. 1 - Titan (Hydrazine/Solids). A variation of the NASA baseline design is presented in Table 3-18. This design combines the reaction control and orbit adjust functions which are performed by a hydrazine propulsion system thereby eliminating the need for a heavy and costly pneumatic system. The hydrazine system is further optimized by combining the propellant contained in four separate tanks into a single larger diameter tank. The thrust level for accomplishing reaction control is increased from the 0.1 lb force level of the baseline design to a 0.25 lb force level in order to utilize a flight qualified engine design. This increased thrust level is fully compatible with the attitude control subsystem.

Alternate No. 2 - Titan (All Hydrazine). An integral all hydrazine reaction control/orbit adjust/orbit transfer system, is shown on Table 3-19. The system utilizes redundant and controllable 150 lb_F hydrazine engines for accomplishing orbit transfer. This low thrust level allows spacecraft stabilization during orbit transfer to be accomplished by either the 5 lb_F orbit adjust engines or the 0.25 lb_F reaction control engines resulting in a system which truly meets the no single point failure requirement. The system employs a propellant

Table 3-18. Alternate No. 1 - Titan (Hydrazine/Solids)

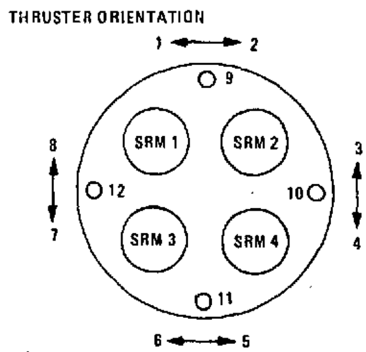
PROPELLANT BUDGET

Initial Stabilization	2.3
Momentum Unloading	26.0
Inject. Error Removal	38.4
Orbit Maintenance	21.0
S/C Control (SRM Burn)	20.9
Velocity Trim	10.0
3δ Perf. & Residuals	2.9
Total	121.5 lbs



SUBSYSTEM WEIGHT

Reaction Control & Orbit Adjust		191.9
Tankage	15.0	
Thrusters	37.6	
Other Hardware	15.3	
Hydrazine	121.5	
Pressurant	2.5	
Orbit Transfer		656.0
Motor 1	169	
Motor 2	166	
Motor 3	162	
Motor 4	159	
Total		847.9 lbs



Motor No.	ΔV Req'd	Prop. Wt	Motor Wt
1	265	142	169
2	266.6	139	166
3	273.8	135	162
4	276.9	132	159
Total		548 lbs	656 lbs

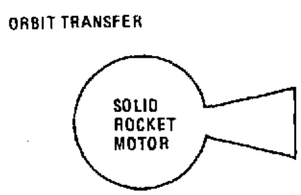
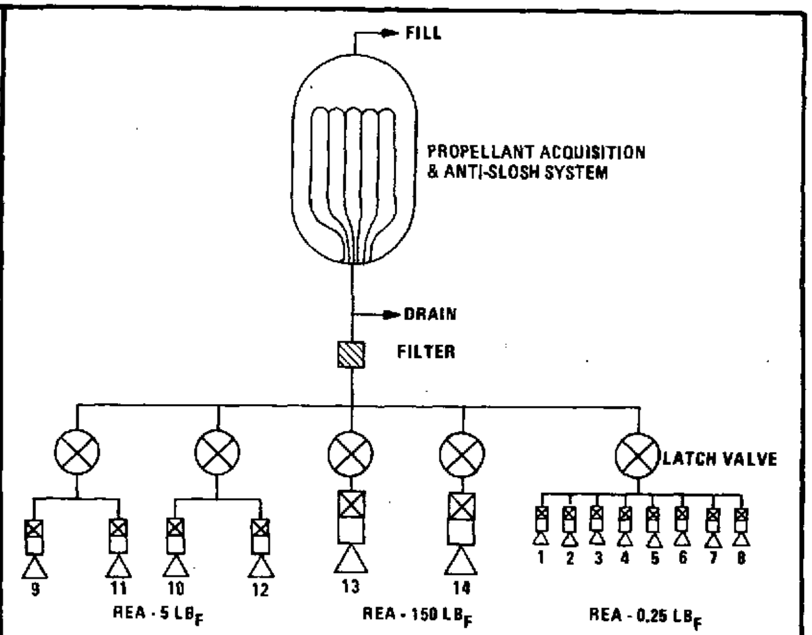


Table 3-19. Alternate No. 2 - Titan (All Hydrazine)

PROPELLANT BUDGET

	Recovery Alt. 300 nm	Recovery Alt. 250 nm
Orbit Transfer	577.0	687.0
Initial Stabilization	2.3	2.3
Momentum Unloading	26.0	26.0
Inject. Error Removal	38.4	38.4
Orbit Maintenance	21.0	21.0
S/C Control (OT Burn)	18.1	21.6
3 σ Pref & Residuals	17.1	19.9
TOTALS	699.9 lbs	816.2 lbs

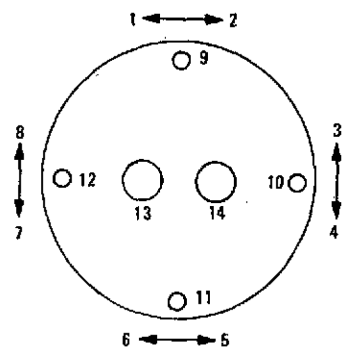


SUBSYSTEM WEIGHT

Tankage	115.0
150 LB_F REA (2)	20.0
5 LB_F REA (4)	8.0
0.25 LB_F REA (8)	5.6
Other Hardware	25.2
Dry Weight	173.8 lbs

	Recovery Alt. 300 nm	Recovery Alt. 250 nm
Dry Weight	173.8	173.8
Hydrazine	699.9	816.2
Pressurant	25.9	22.5
Subsystem Total	899.6 lbs	1012.5 lbs

THRUSTER ORIENTATION



slosh control, CG predictability and propellant expulsion when subjected to all orbital mission environments.

Alternate No. 1 - Delta (Nitrogen/Hydrazine). A propulsion subsystem design utilizing gaseous nitrogen for reaction control and liquid hydrazine for orbit adjust and orbit transfer functions was studied for the Delta launched EOS spacecraft. A block diagram and weight summary for this system is presented on Table 3-20. The system is capable of transferring the spacecraft to a retrieval altitude of 300 nm and with an increased propellant load of 59 lbs will transfer to 250 nm. The system offers redundancy for the orbit transfer function, however, the capability of the reaction control subsystem to supply the required backup to the orbit adjust subsystem is marginal at a thrust level of 0.1 lb_F. Adequate redundancy could be achieved if the thrust level were increased to 0.2 lb_F.

Alternate No. 2 - Delta (All Hydrazine). An alternate to the nitrogen/hydrazine propulsion subsystem is the integral hydrazine system presented in Table 3-21. The system is identical to the system previously described for Titan except that the orbit transfer engine thrust level is lowered to 100 lb_F and the single large propellant tank is replaced with two smaller off-the-shelf type tanks. These changes accomplish a more optimum and cost-effective design for the 2,200 lb EOS spacecraft.

3.3.3 PROPULSION SYSTEM DESIGN COSTS

Non-recurring, recurring and refurbishment costs for the three Titan IIIB and the two Delta 2910 compatible propulsion system designs are presented in Tables 3-22 and 3-23, respective Table 3-24 presents cost data for propulsion systems compatible with a Delta launch for whicl the orbit transfer function is deleted, i.e., spacecraft retrieval is accomplished at mission altitude. An all gaseous nitrogen design was included because of the small ΔV requirement for this mission option. Using these subsystem cost data, cost trades based on a single EOS-A flight and/or the total EOS program are contained in Tables 3-25 and 3-26. In all cases the integral all-hydrazine propulsion subsystem affords the design exhibiting the lowest cost.

Table 3-20. Alternate No. 1 - Delta (Nitrogen/Hydrazine)

SUBSYSTEM WEIGHT

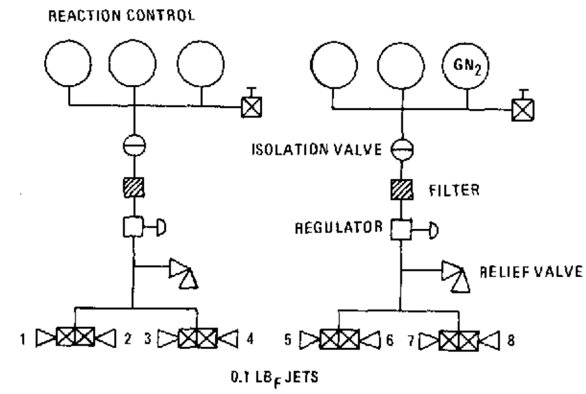
Reaction Control	Retrieval 300 nm	Altitude 250 nm
Tankage	94.8	94.8
Thrusts	5.6	5.6
Other Hardware	20.5	20.5
Gaseous Nitrogen	42.4	42.4
REACTION CONTROL TOTAL	163.3 lbs	163.3 lbs

Orbit Adjust & Orbit Transfer	Retrieval 300 nm	Altitude 250 nm
Injection Error Removal	20.5	20.9
Orbit Maintenance	7.0	7.0
Orbit Transfer	127.8	185.7
S/C Control During O.T. Burn	4.9	6.6
-3σ Perf. & Residuals	4.0	5.5
TOTAL	164.2 lbs	225.7 lbs

PROPELLANT BUDGET

Reaction Control		
Initial Stabilization & Restab.	5.8	
Momentum Unloading	32.5	
Residuals & Leakage	4.1	
TOTAL	42.4 lbs	
Orbit Adjust & Orbit Transfer		
Tankage	30.0	30.0
100 lb_F REA (2)	20.0	20.0
5 lb_F REA (4)	8.0	8.0
Other Hardware	24.7	24.7
Propellant	164.2	225.7
Pressurant	6.6	4.9
OA/OT TOTAL	253.5	313.3
PROPULSION SUBSYSTEM TOTAL	416.8 lbs	476.6 lbs

BLOCK DIAGRAM



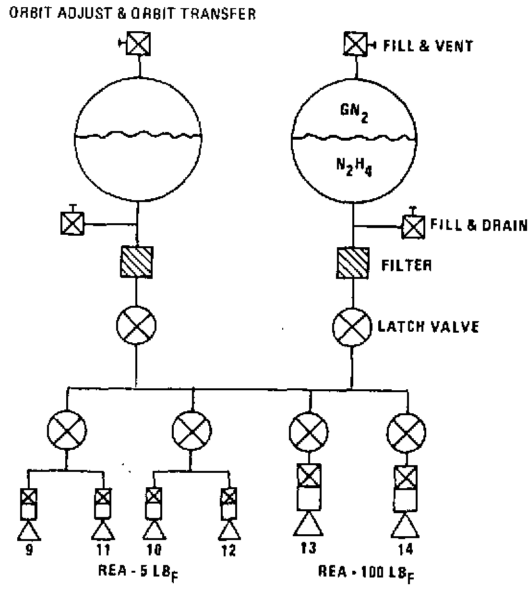


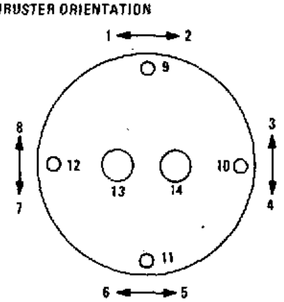
Table 3-21. Alternate #2 - Delta (All Hydrazine)

PROPELLANT BUDGET	Retrieval Altitude 300 nm	250 nm
Injection Error Removal	19.3	19.7
Initial Stabilization & Restab.	2.3	2.3
Momentum Unloading	13.0	13.0
Orbit Maintenance	7.0	7.0
Orbit Transfer	121.4	176.6
S/C Control During O.T. Burns	4.4	6.1
-3 σ Performance & Residuals	4.2	5.6
TOTAL	171.6 lbs	230.3 lbs

SUBSYSTEM WEIGHT	Retrieval Altitude 300 nm	250 nm
Propellent Weight	171.6	230.3
Pressurant Weight	6.4	4.8
Dry Weight	88.8	88.8
TOTAL	266.8 lbs	323.9 lbs

HARDWARE WEIGHT	
Tankage	30.0
100 lb_F REA (2)	20.0
5 lb_F REA (4)	8.0
0.25 lb_F REA (8)	5.6
Other Components	25.2
TOTAL	88.8 lbs

THRUSTER ORIENTATION



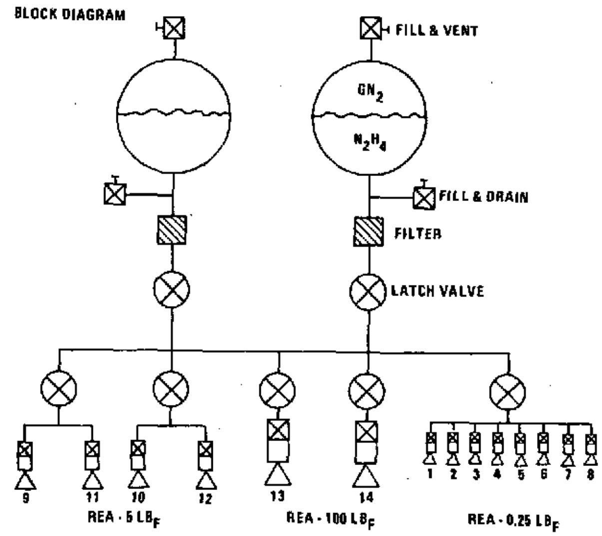


Table 3-22. Propulsion System Costs for a Titan IIIB Launched Spacecraft

Design Configuration	Non-Recurring Costs (K$)	Recurring Costs (K$)	Refurbish Costs (K$)
NASA Baseline (GE Cost Estimate)			
Reaction Control	550	235	
Orbit Adjust	925	335	
Orbit Transfer	100	232	
Syst. Integ., Structure, Harness	900	200	
Total	2,475	1,002	400
Alternate No. 1 (Hydrazine/Solids)			
RC/OA	1,375	475	
Orbit Transfer	100	232	
Syst. Integ., Structure, Harness	730	190	
Total	2,205	897	350
Alternate No. 2 (Hydrazine)			
RC/OA/OT	1,600	550	
Syst. Integ., Structure, Harness	560	130	
Total	2,160	680	120
NASA Baseline (Boeing Cost Estimate)			
Reaction Control		76	
Orbit Adjust		156	
Orbit Transfer		240	
Syst. Integ., Structure, Harness		178	
Total	5,000	650	400

Table 3-23. Propulsion System Costs for a 2910 Delta Launched Spacecraft
Shuttle Retrieval at 300 Nm Altitude
($X 1000)

Design Configuration	Non-Recurring Costs ($)	Recurring Costs ($)	Refurbish Costs ($)
Alternate No. 1 (Nitrogen/Hydrazine)			
Reaction Control	525	210	
Orbit Adjust & Orbit Transfer	1,320	350	
Syst. Integ., Structure, Harness	560	130	
Total	2,405	690	110
Alternate No. 2 (Hydrazine)			
RCS/OA/OT	1,375	470	
Syst. Integ., Structure, Harness	560	130	
Total	1,935	600	

Table 3-24. Propulsion System Costs for 2910 Delta Launched Spacecraft Shuttle Retrieval at Mission Altitude

Design Configuration	Non-Recurring Costs (K$)	Recurring Costs (K$)	Refurbish Costs (K$)
All Gaseous Nitrogen Design			
Reaction Control & Orbit Adjust	950	330	
Syst. Integ., Structure, Harness	560	130	
Total	1,510	460	65
Alternate No. 1 (Nitrogen/Hydrazine)			
Reaction Control	525	210	
Orbit Adjust	920	200	
Syst. Integ., Structure, Harness	560	130	
Total	2,005	540	80
Alternate No. 2 (Hydrazine)			
Reaction Control & Orbit Adjust	970	320	
Syst. Integ., Structure, Harness	560	130	
Total	1,530	450	65

Table 3-25. Propulsion System Cost Trade for a Titan IIIB Launched EOS Spacecraft

Costing Assumptions
- NR - Includes Qual Unit
- REC - Four Flight Units
- REF - Refurbish Flight Units for 10 Addit. Flights

Design	Non-Recurring	Recurring	Refurbish	EOS A One Flight	Total Prog
NASA Baseline (Boeing)	5,000K	650K	400K	5,650K	11.6M
(GE)	2,475K	1,002K	400K	3,477K	10.5M
(Lowest)	2,475K	650K	400K	3,125K	9.1M
Alternate No. 1 (N_2H_4 & Solid)	2,205K	897K	350K	3,102K	9.3M
Alternate No. 2 (N_2H_4)	2,160K	680K	120K	2,840K	6.1M

Total System Cost

NASA Baseline (Boeing)	5,000 + 4 (650) + 10 (400) = 5,000 + 2,600 + 4,000 = 11,600K
(GE)	2,475 + 4 (1002) + 10 (400) = 2,475 + 4,008 + 4,000 = 10,483K
(Lowest)	2,475 + 4 (650) + 10 (400) = 2,475 + 2,600 + 4,000 = 9,075K
Alternate No. 1 (N_2H_4 & Solids)	2,205 + 4 (897) + 10 (350) = 2,205 + 3,588 + 3,500 = 9,293K
Alternate No. 2 (N_2H_4)	2,160 + 4 (680) + 10 (120) = 2,160 + 2,720 + 1,200 = 6,080K

Note - These costs do not include added costs to solid motor systems to accommodate range of missions after EOS A

Table 3-26. Propulsion System Trade Summary for a Delta Launched EOS Spacecraft

Costing Assumptions

NR - Includes Qual Unit
REC - Four Flight Units
REF - Ref. Flight Units for 10 Add Flts.

Design	Costs in M$ Non-Recurring	Recurring	Refurbish	EOS A One Flight	Total Program
Retrieval at Mission Alt.					
All Gaseous Nitrogen	1.510	.460	.065	1.970	4.000
Alternate No. 1 (Nitrogen/Hydrazine)	2.005	.540	.080	2.545	4.965
Alternate No. 2 (Hydrazine)	1.530	.450	.065	1.980	3.980
Retrieval at 300 Nm Alt.					
Alternate No. 1 (Nitrogen/Hydrazine)	2.405	.690	.110	3.095	6.265
Alternate No. 2 (Hydrazine)	1.935	.600	.100	2.535	5.335

3.3.4 PROPULSION SUBSYSTEM SELECTION

The evaluation criteria used in performing the EOS propulsion system design trade are the following:

1. Cost
2. Weight
3. Mission Felxibility
4. Growth Potential
5. Development Risk
6. Reliability and Simplicity
7. Shuttle Compatibility
8. Design Modularity

9. System Safety

10. Impact on Vehicle & Other Subsystem Design

Evaluation and ranking of the alternative propulsion system designs is contained on Table 3-27. The evaluation is made on a numerical basis with the number 1 being the best.

Table 3-27. Propulsion System Evaluation and Ranking

	Titan Configurations			Delta Configurations		
Evaluation Criteria	NASA Baseline	Alternate No. 1	Alternate No. 2	All Gaseous Nitrogen	Alternate No. 1	Alternate No. 2
System Cost	3	2	1	1	2	1
System Weight	3	1	2	3	2	1
Mission Flexibility	2	2	1	2	2	1
Growth Potential	2	2	1	3	2	1
Development Risk	1	1	1	1	1	1
Reliability & Simplicity	2	2	1	1	2	1
Shuttle Compatibility	1	1	1	1	1	1
Design Modularity	1	1	1	1	1	1
System Safety	1	1	1	1	1	1
Vehicle Design Impacts	2	2	1	1	1	1
Overall Rank	3	2	1	2	2	1

The Alternate No. 2 design is selected as the preferred propulsion system for either the Titan or Delta launched spacecraft. The significant factors which led to the selection are as follows:

1. <u>System Cost.</u> Lowest cost of the designs.

2. <u>Design Modularity.</u> System is readily adaptable to either the Delta or the Titan/Atlas family of launch vehicle constraints.

3. Growth Potential. The propellant tankage is sized such that the mission propellant load can be increased (depending upon the type of pressurization system design) over mission propellant requirements.

4. Mission Flexibility. Mission and retrieval altitudes can be changed (within tankage capacity limits) during the course of spacecraft development with no impact upon the propulsion system design.

5. Shuttle Compatibility. The all hydrazine design is the only design presented that meets the no-single point failure for shuttle retrieval requirement.

6. Development Risk. Except for the orbit transfer engines, all hardware proposed for the all hydrazine design has been developed and qualified for other spacecraft programs. Large orbit transfer engines are presently being developed by multiple suppliers and should present no development risk.

3.4 WIDEBAND COMMUNICATIONS AND DATA HANDLING DESIGN/COST TRADEOFFS

The design/cost tradeoffs considered can be catagorized into two areas; first, internal cost optimization tradeoffs primarily affecting the wideband communication and data handling subsystems and second, system level tradeoffs which have impact across several subsystems. In the first category, cost tradeoffs were conducted to (1) examine alternate modulation schemes, (2) tradeoff high power versus low power modulation, (3) cost optimize power amplifier and antenna gains and (4) consider techniques to improve link performance. A fifth cost study considered the cost and type of redundancy. In the second category, three major areas were investigated; (1) the impact of various data rates to low cost user stations, (2) the impact of TDRSS versus on-board recording, and (3) the impact of various system considerations on wideband handling and compaction. These tradeoff areas are discussed in order in the following sections. The requirements and assumptions used in these tradeoffs include:

Operating frequency	X-Band: 8.025-8.40 GHz
STDN link data rate	240 Mbps (nominal)
LCU link data rate	20 Mbps (nominal)
Bandwidth (both STDN & LCU)	375 MHz
C.C.I.R. Power Flux Density limitations	

3.4.1 MODULATION TRADEOFFS

The cost/performance implications of four modulation techniques were evaluated for both the NASA STDN and the low cost user links. These candidate techniques are:

PCM/FM - Pulse Code Modulation/Frequency Modulation
QPSK - Quadriphase Shift Key
BPSK - Bi-phase Shift Key
MSK - Minimum Shift Key

A block diagram of each technique examined is shown in Figure 3-22.

PCM/FM. This modulation method is employed on the ERTS wideband link. The AFC loop, used on ERTS, was deleted in order to decrease cost and power consumption. As such the hardware may be considered "space proven" and not require requalification for EOS. Measured data confirms that with an RF bandwidth to bit rate ratio of 1.3, a 10^{-5} BER is obtained with a S/N ratio of 14 dB.

QPSK. The QPSK modulator consists of a pair of summed BPSK modulators in phase quadrature. The demodulator is a modified "costas" loop. The approach shown will handle two asynchronous data streams. Equipment has been developed and evaluated at bit rates of 1000 Mbs, four times the EOS requirement. A computer simulation developed by GE and analysis which considers worst case hardware anomalies (AM/PM conversion, phase and amplitude unbalances, bandwidth limiting, etc.) predicts a 10^{-5} BER at a S/N ratio of 13.4 dB and a bandwidth to bit rate ratio of 1.1.

BPSK. This modulator is obtained by removing one DBM from the QPSK modulator. The demodulator is a "costas" loop. As in QPSK, equipment has been demonstrated at bit rates of 1000 Mbs. The bandwidth required is much greater than QPSK. Equipment has been demonstrated that yields a 10^{-5} BER at a S/N ratio of 12 dB and a bandwidth to bit rate ratio of 1.5.

MSK. A number of MSK implementations are available in the literature. None have been reported reduced to practice at a 240 Mbs rate. Birch's (1) MSK modulator/demodulator is shown in Figure 3-22. The modulator provides cosine weighted amplitude modulation of phase-orthogonal carriers required for MSK. In the demodulator f_1 and f_2, the two FSK sidebands, are used to demodulate the I and Q channels.

It is estimated that a 10^{-5} BER may be obtained at a S/N ratio of 12.5 dB and at a bandwidth equal to the bit rate. This based on the assumption that bandwidth limiting will have a negligible effect on the MSK spectrum under these conditions.

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(1) J. N. Birch, "Comparison of Coherent and Non-Coherent Detection of Phase, Continuous Binary FM Signals," ITC-72, p20D-1 to 20D-6.

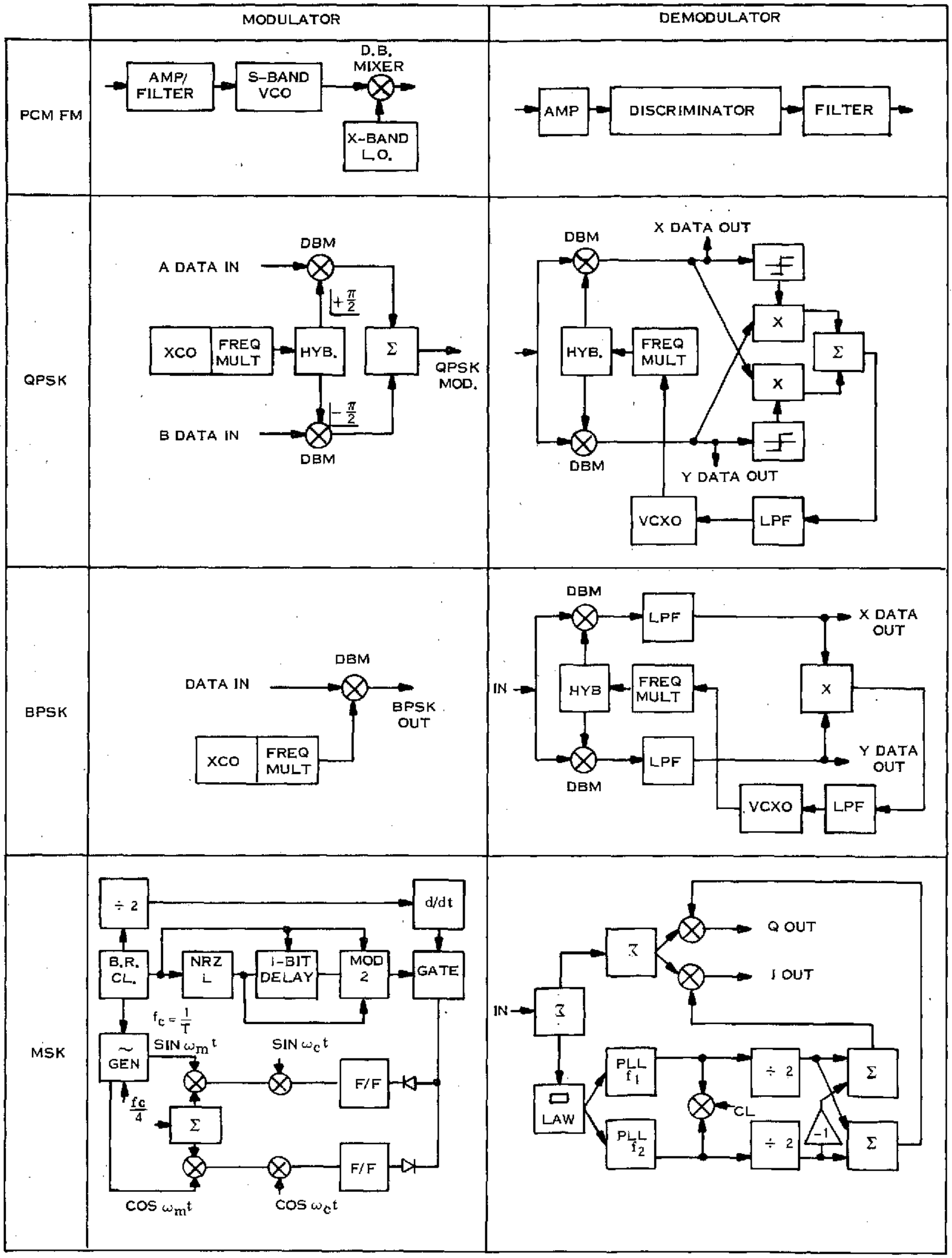

Figure 3-22. Alternate Modems

Evaluation and Recommendation. Table 3-28 summarizes the performance and cost results of the tradeoff. Given the fixed bandwidth restriction of 375 MHz and the data rates indicated it is very desirable that the 240 MBS modulation candidates be highly conservative of RF bandwidth. BPSK may be eliminated immediately and PCM/FM leaves little guard band between NASA STDN and LCU links. QPSK is recommended for the 240 MBS link since the modest performance improvement does not justify the increased cost and risk of MSK.

Bandwidth conservation is not critical in the LCU link since it occupies a relatively small portion of the total. Cost and availability are better criteria. This suggests BPSK or PCM/FM for the LCU. PCM/FM is recommended since the performance is roughly equivalent to BPSK and cost/risk factor is considerably less.

3.4.2 HIGH VERSUS LOW LEVEL QPSK MODULATION

Figure 3-23 depicts a QPSK modulator/amplifier where modulation is performed at a low level (1-5 mw) and the signal amplified to the 1 to 5 watt range with a power amplifier. This approach is well within the "state-of-the-art." The equipment, exclusive of the TWT and filters, however, will have to be reduced to flight qualified hardware at an estimated cost of \$ 360-K. Recurring system cost including power amplifier and filter is \$ 138-K. Power required is about 25 watts.

Figure 3-24 shows an approach which modulates the high level signal generated by an injection locked high level GaAs diode X-band oscillator. No power amplifier or up convertor is required. Present performance estimates show that a 20% efficiency is obtainable from a 8.5 GHz source at a 5 watt level. It is anticipated that greater efficiencies will be achieved in the future. However, overall performance has not been demonstrated. No diode switch is available at present to handle the power level/data rate so that a considerable technology development is necessary.

Table 3-28. Modulation Performance/Cost Summary

Comparative Parameters: Modulation Candidate	RF Band-Width	S/N 10^{-5} BER	Performance RF Spectrum Attenuation with Frequency (Random Data)	Remarks	ROM Modulator Cost (Redundant): Non Recur	Recur	Conclusion
PCM/FM D = 0.7	1.3 BR	14 dB	$\frac{1}{\Delta f^4}$	ERTS 15 MBS Power = 7.1 W	95 K	62 K	Lowest cost. Qualified hardware & space proven performance (ERTS). < B.W. BPSK > B.W. MSK. Recommend for LCU since B.W. & S/N not significant cost impact.
QPSK	1.1 BR	13.4 dB	$\frac{1}{\Delta f^2}$	Computer Simulation & Analysis Power = 8 W	360 K	88 K	Lower cost, less complexity, & less risk than MSK. Slightly poorer performance. Proven hardware at 1 GHz. Recomm. for 240 MBS link. May accommodate asynchronous data stream.
BPSK	1.5 BR	12 dB	$\frac{1}{\Delta f^2}$	Estimate (S/N, 2.4 dB implementation margin) Power = 6.0 W	300 K	75 K	Highest B.W.; best S/N. Not recommen. for either link.
MSK	BR	12.5 dB	$\frac{1}{\Delta f^4}$	Estimate S/N 0.9 dB QPSK with B.W. limiting Power > QPSK	1 to 1.5M	175K	Modest potential perform Improve over QPSK. More complex, highest cost & greatest risk. Unproven hardware at 240 MBS. Will not accommodate asynchronous data stream.

$\Delta f = \Delta$ from carrier   BR = Bit Rate

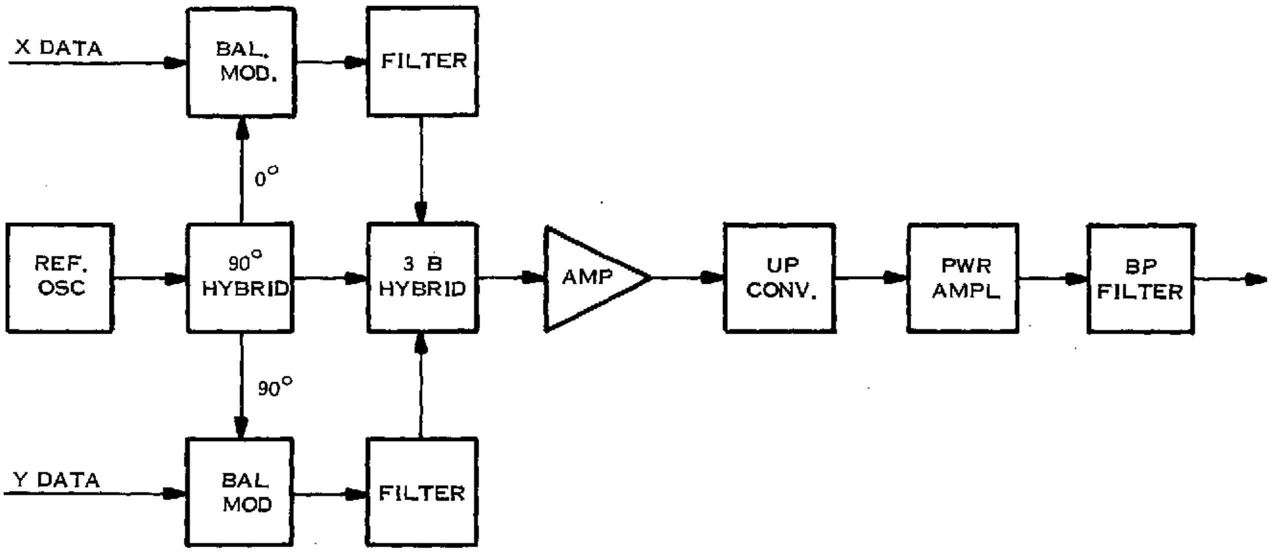

Figure 3-23. Low Level QPSK Modulator/Amplifier

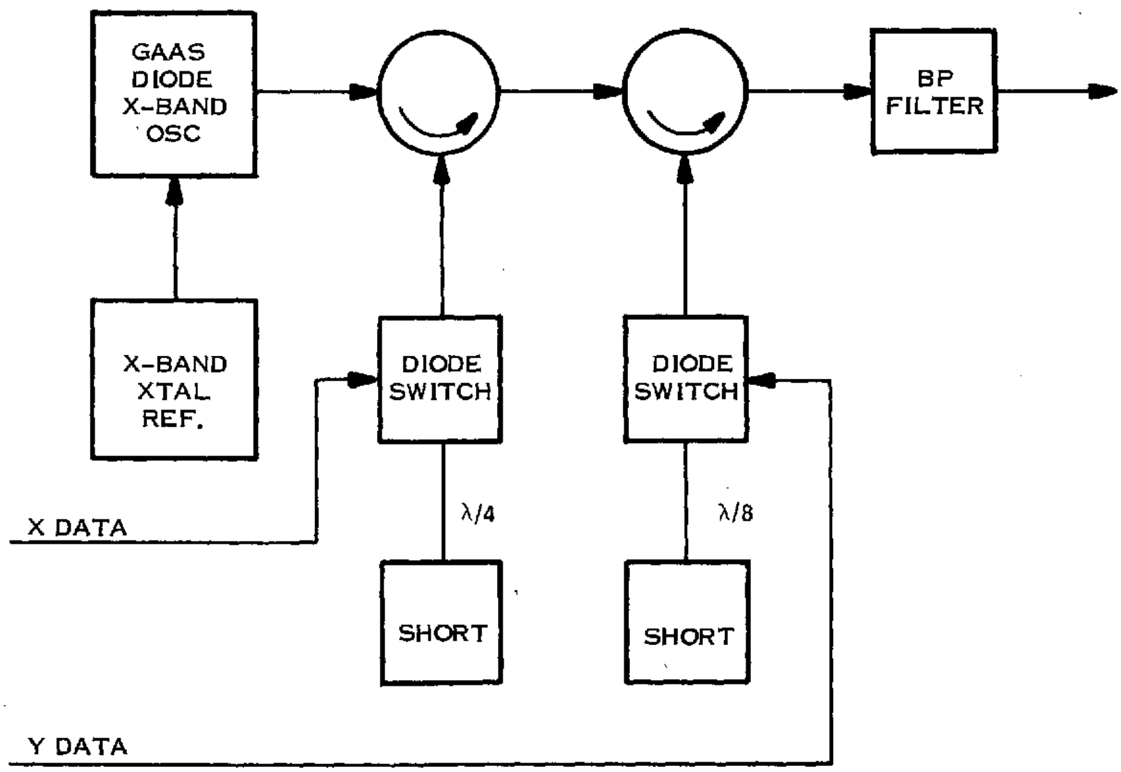

Figure 3-24. High Level QPSK Modulation Approach

An all solid state modulator at high RF levels appears attractive because of its simpoicity. It could offer a power and recurring cost savings. However, it is not possible at this time to reliably estimate the cost of developing this modulation technique at 8 GHz and at a 240 Mbs rate. One million dollars is probably conservative. Thus the low level mod/amp is recommended.

3.4.3 POWER AMPLIFIER VERSUS ANTENNA GAIN

A given EIRP may be achieved by employing a wide range of power amplifier/antenna combinations; since EIRP = $G_{ant} \times P_{amp}$. However, the higher gain antenna will require greater positioning precision and more complex deployment. Higher power amplifiers cost more and consume more spacecraft bus power. It is desirable to investigate the most cost-effective equipment compliment necessary to yield the required EIRP.

A limited choice of space qualified TWTA's is available in the 8 to 8.5 GHz region. Three are available which meet requirements without modification. These were used to synthesize system design costs as shown in Table 3-29. Antenna drive mechanisms and deployment cost varied with pointing accuracy and size. A Delta launch vehicle was assumed in estimating antenna storage/deployment costs. Minimum total system recurring cost is achieved for the nominal 3.3 watt amplifier and 1.7 ft. (5.5° beamwidth) dish.

Table 3-29. System Design Costs

Power Amplifier			Antenna/Drive Deployment			Total System Cost	
Power Output (watts)	Recurring Cost ($K)	Spacecraft Power ($K)	Size (ft.)	Pointing Accuracy (deg.)	Recurring Cost ($K)	Recurring Cost ($K)	Non-Recurring Cost
1	55	3.3	3	0.3	271	329	highest
3.3	80	11	1.7	0.55	207	298	middle
22	90	73	0.7	1.4	178	341	lowest

3.4.4 WIDEBAND LINK PERFORMANCE PARAMETERS VERSUS COST

In any real system the components and devices handling the QPSK signal will cause some degradation. Table 3-30 summaries the various sources of degradation and gives an estimation of the expected magnitude based on currently available hardware. It is desirable to consider whether it would be more cost effective that these signal impairments should be improved at the source, compensated for by increasing transmitted power or equalized in some manner at the ground station receiver.

An inspection of Table 3-30 shows the main sources of degradation are due to the filtering and bandwidth limiting operations as follows:

Total Transmit Filter	-	0.9 dB
Total Receiver Filter	-	0.9 dB
Bandwidth Limiting	-	0.9 dB
All Others	-	1.1 dB
Total (1.75 + 2.05)	-	3.8 dB

Filtering degradation may be improved to some extent by relaxing the filter requirements. This however, would have little cost impact since relatively little cost differential exists between filter types. One may only gain significant cost savings by eliminating the filters entirely and this would not be acceptable since interchannel crosstalk and out of band spurious requirements could not be met.

The equalization of filter characteristics (amplitude ripple, parabolic phase and cubic phase) has been demonstrated. This technique is also effective in reducing AM/PM conversion and modulator and demodulator phase errors. Furthermore, equalization may be made adaptive and thereby remove time variations in these parameters. It is estimated that a five section adaptive equalizer can improve the S/N degradation of the EOS link by around 1.7 dB. Such a unit incorporated at the ground station would cost ROM \$ 10-K. This would allow a spacecraft power reduction of from 4.0 to 2.7 watts. This in itself does not justify the cost. However, adaptive equalization may allow selection of a less expensive power

Table 3-30. QPSK Link Degradation Summary

Degradation Source	Transmitter		Receiver	
	Specification	Degradation (dB)	Specification	Degradation (dB)
Short-Term Freq. Stability	1 deg rms, 500 KHz PLL	0.05	1 deg rms, 500 KHz PLL	0.05
Phase Jitter Due to Thermal Noise	--	--	1 deg rms	0.05
Static Phase Error	--	--	$\pm$ 2 deg	0.10
Modulator Phase Unbalance	$\pm$ 2.5 deg	0.15	2	1
Modulator Amplitude Unbalance	$\pm$ 3%	Neglig.	--	--
Modulator Rise Time	0.1 x symbol period	0.25	--	--
AM/PM Conversion Factor	6 deg/dB	0.20	--	--
Bandwidth Limiting and Data Detector Mismatch	300 MHz (min)	--	300 MHz (min)	0.90
Amplitude Variation (over $\pm$ 120 MHz)	1 dB Tilt 1.5 dB p-p Ripple	Neglig. 0.15	1 dB Tilt 1.5 dB p-p Ripple	Neglig. 0.15
Parabolic Phase	15 deg	0.25	15 deg	0.25
Cubic Phase	15 deg	0.15	15 deg	0.15
Phase Ripple	12 deg	0.35	12 deg	0.35
Data Asymmetry	1.1	0.15	--	--
Clock Stability	6 deg rms, 10 KHz PLL	0.05	6 deg rms, 10 KHz PLL	0.05
Data Synchronization	Skewed 0.5 bit $\pm$ 0.25 bit	Included in AM/PM Factor	--	--
Total Degradation		1.75 dB	--	2.05 dB

amplifier and may be an effective means for increasing link margin for certain hardware impairments that change with time.

3.4.5 IMPACT OF REDUNDANCY ON WIDEBAND SUBSYSTEM COST

The cost of various levels of redundancy in the wideband subsystem were examined. The alternate configurations are shown in Figure 3-25.

Configuration No. 1 shows the minimum equipment required for two independent RF links, 240 Mbs and 20 Mbs. NASA station "handover" requires antenna slew and reacquisition with attending data loss.

Configuration No. 2 includes four latching circulators allowing either modulator to use either link, however, cross-link operation is not simultaneous. This allows for a rapid "handover" since antenna A may be pointed while antenna B is available for LCU stations. A time shared backup is available in the event of a gimbal or TWT failure.

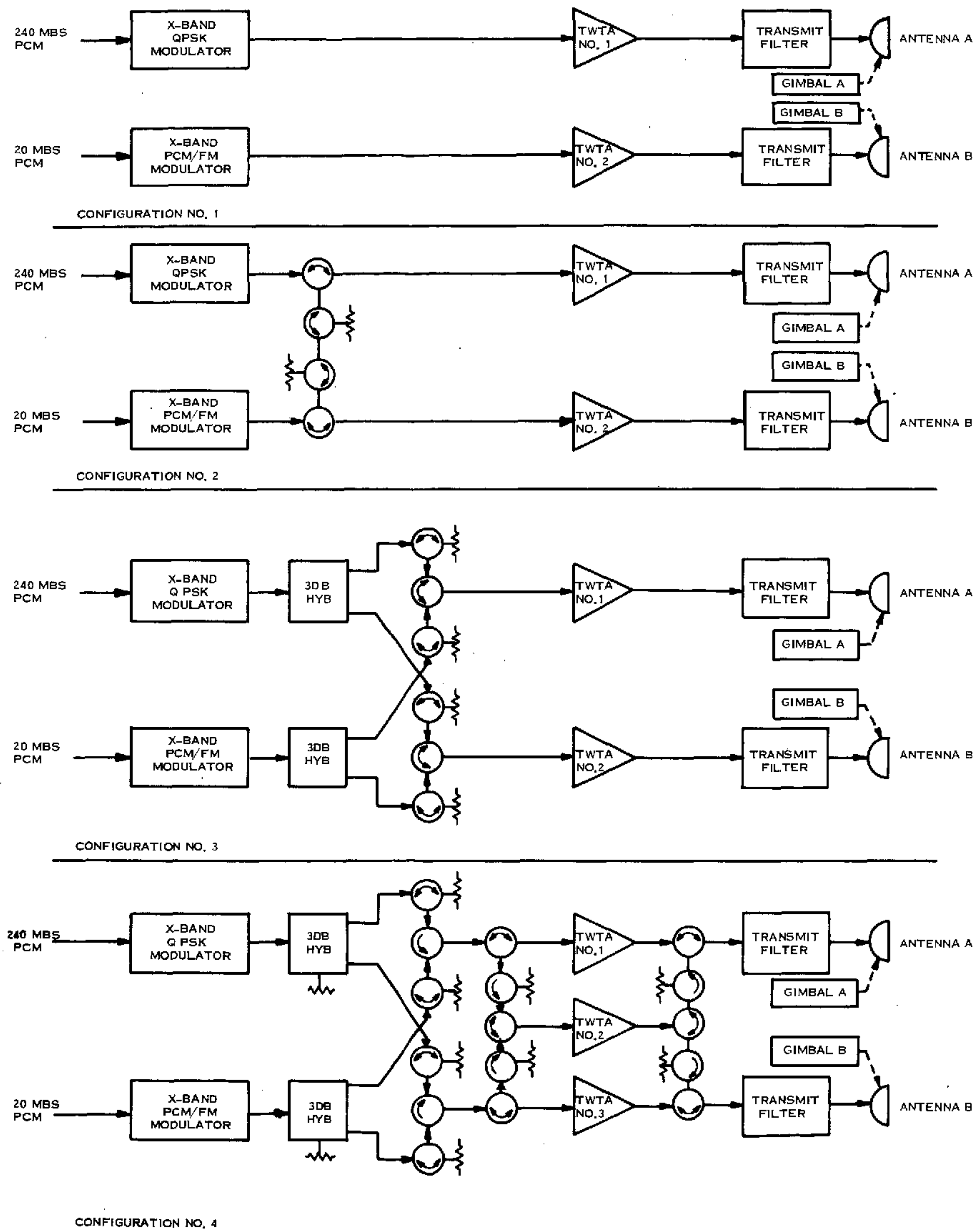

Figure 3-25. Wideband System Redundancy

Configuration No. 3 offers an additional capability. It allows cross link operation to be simultaneous.

Configuration No. 4 backs up TWT failures in either link with a third TWT.

Configuration No. 5 (not shown) employs redundant modulators added to Configuration No. 4.

The ROM delta costs of each configuration over the baseline are summarized in Table 3-31. The power consumption and weights are shown for reference. Configuration No. 3 is recommended since the capability offered is attractive for the modest cost incurred.

Table 3-31. Redundancy Cost Summary

		Delta Recurring Costs ($ K)	Power (watts)	Weight (pound)
Configuration 1	Non-Redundant Slow handover No backup modes	REF	REF	REF
Configuration 2	Mod Switching Time Share BU (TWT & Gimbal) Rapid handover No Mod BU	15	0	3
Configuration 3	Mod Cross Switching Time Share BU Rapid handover No Mod BT	22	0.0	4.6
Configuration 4	Redundant Except Mods All (3) plus TWT BU	137	15.3	18.1
Configuration 5	Fully Redundant All (4) + Mod BU	222	30.4	27.1

3.4.6 IMPACT OF LCU DATA RATE ON WIDEBAND SUBSYSTEM COST

The total bandwidth available (375 MHz) is apportioned between the 240 MBS and the compacted, nominally 20 MBS, data. The cost impact of compacted data rates in the range of 8 to 40 MBS have been assessed assuming the 240 MBS rate held constant. The approach used was to establish the delta costs to go to either 8 or 40 MBS from a 20 MBS base design.

Baseline System Requirements and Assumptions. Figure 3-26 illustrates the baseline filtering configuration required to meet the output of band spurious and cross talk requirements. The following analysis, results and assumptions apply:

1. 240 MBS modulation is QPSK and LCU modulation is PCM-FM.
2. Antenna gain is constant for the LCU link and the same as the 240 MBS antenna.
3. RF isolation between links is achieved by bandpass filtering at the modulator output (as opposed to pre-modulation filtering).
4. 240 MBS link to LCU cross talk is based on a 1010 ... pattern (worst case) in the 240 MBS link.
5. A 5 pole 0.1 dB cheby-chev filter is required for the 240 MB link.
6. A 4 pole 0.1 dB cheby-chev filter is required for the 20 MB link.

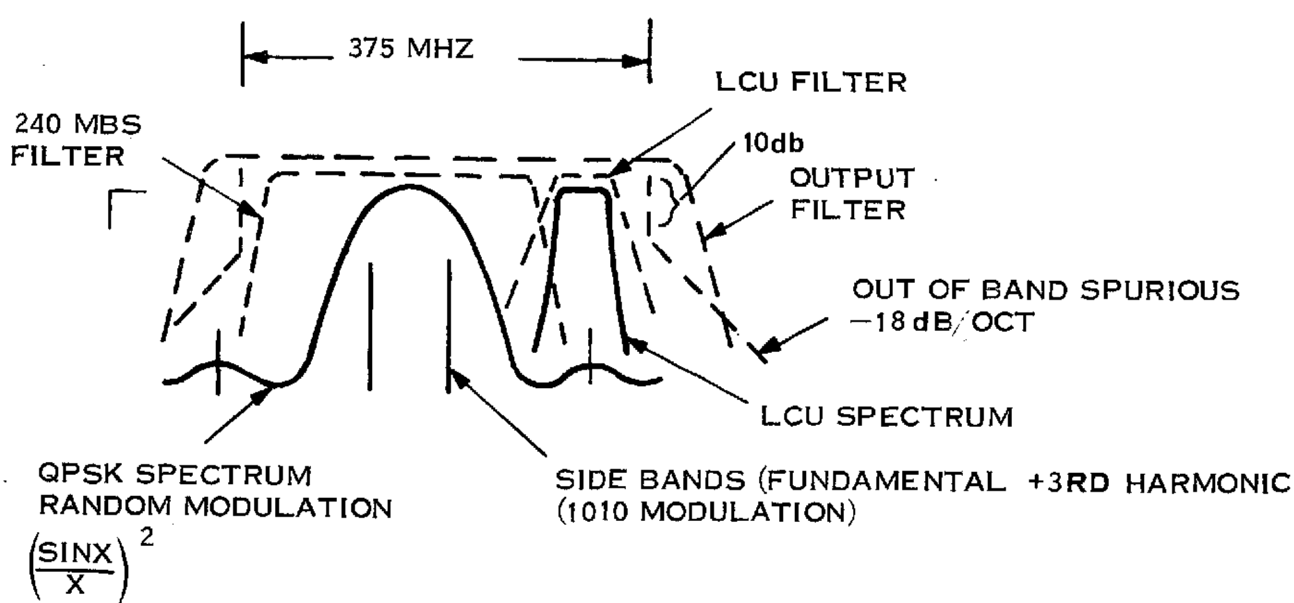

Figure 3-26. Interchannel Filtering Requirement

8 MBS Rate. Assuming that the required bandwidth is proportional to bit rate then the new bandwidth is 12 MHz. This allows elimination of the LCU filter, however a wideband filter is still recommended. The power reduction (0. 16 watts) is negligible.

40 MBS Rate. The required bandwidth is 60 MHz and since $\frac{P_t}{\Delta f} \leq K$ one may either increase the LCU station antenna, and/or decrease the receiver noise temperature to accommodate the reduced ground PFD, or increase the spacecraft power by 3 dB. An increase in P_t to 0. 8 watts appears well within the capability of the lowest power space qualified TWT available. This therefore appears to be the lowest cost route.

The increase in bandwidth will however introduce an additional filtering problem and require narrowing of the 240 MBS RF spectrum. The inclusion of polarization isolation (15 to 25 dB cross talk improvement) is very attractive in this case to alleviate the filtering requirement. The significant cost impact, however, involves the development of a space qualified PCM - FM modulator at 40 MBS.

Cost Comparison. Table 3-32 shows the total cost deltas (with recurring and non-recurring) for the cases analyzed. Assuming PCM-FM modulation using an existing modulator, costs will vary only slightly for data rates within the capability of this equipment. Modulator development cost will be incurred above 20 MBS.

Table 3-32. Cost Comparison

Bit Rate LCU (MBS)	B.W. LCU (MHz)	B.W. 240 MBS (MHz)	Power P_t (w) LCU	Δ Cost
8	12	295	0. 16	-7 K
20	30	280	0. 4	Reference
40	60	280	0. 8	+ 310 K

3.4.7 IMPACT OF WBVTR/TDRSS

An assessment was made to determine the added wideband subsystem complexity/cost to provide global coverage capability using either on-board WBVTR's or a TDRSS relay link. The baseline was assumed to be a direct satellite to ground station configuration. Payload complement and number of WBVTR's used are based on the revised mission definition and GSFC guidelines.

The solid line portion of Figure 3-27 shows the WBVTR configuration for an instrument complement of one TM and one MSS. For the "operational" part of the system real time or stored MSS data is transmitted to a DOI station either at Sioux Falls or Alaska using a steerable high gain dish. The baseline system simply requires deletion of the two 15 MBS tape recorders and some of the switching. The "R&D" part of the system transmits TM data to one of the STDN stations at either Goldstone, Alaska and NTTF thru a second steerable high gain antenna. Compacted LCU data is transmitted thru a fixed shaped beam antenna. The 200 MBS High Density Multitrack Recorder (HDMR) is deleted for the baseline configuration. Capability for switching either compacted TM or MSS data into the LCU link is also provided. The STDN and DOI data paths are cross-strapped as shown. The TM plus 2 MSS configuration requires the addition of the equipment shown in the dotted lines of Figure 3-27 for either the baseline or WBVTR version.

Figure 3-28 shows the TDRSS configurations for either of the two payload complements. An assumption was that back-up real time capability must be provided in addition to the TDRSS links.

Frequency multiplexing is employed to combine TWTA outputs. Digital multiplexing prior to RF amplification is being considered as an alternate since it will be more conservative of bandwidth and reduce the number of TWTA's required.

The TDRSS spacecraft will provide two steerable 12 foot antennas, each equipped with dual S- and Ku-band feeds. The means by which TDRSS acquires and tracks EOS is presumed to be via open loop pointing while a ground station computer controlled scan with AGC

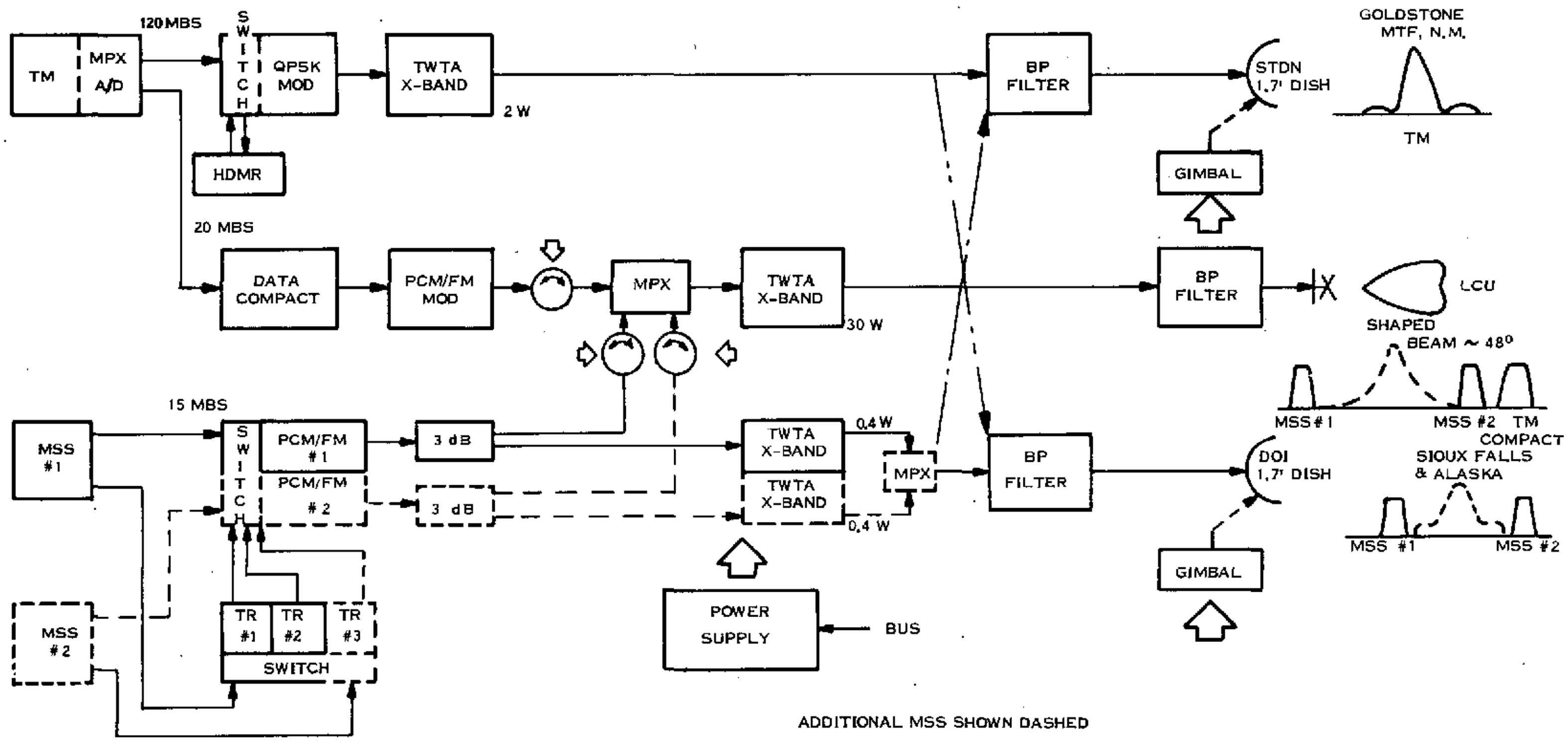

Figure 3-27. Baseline
(TM + 1 MSS & TM + 2 MSS)

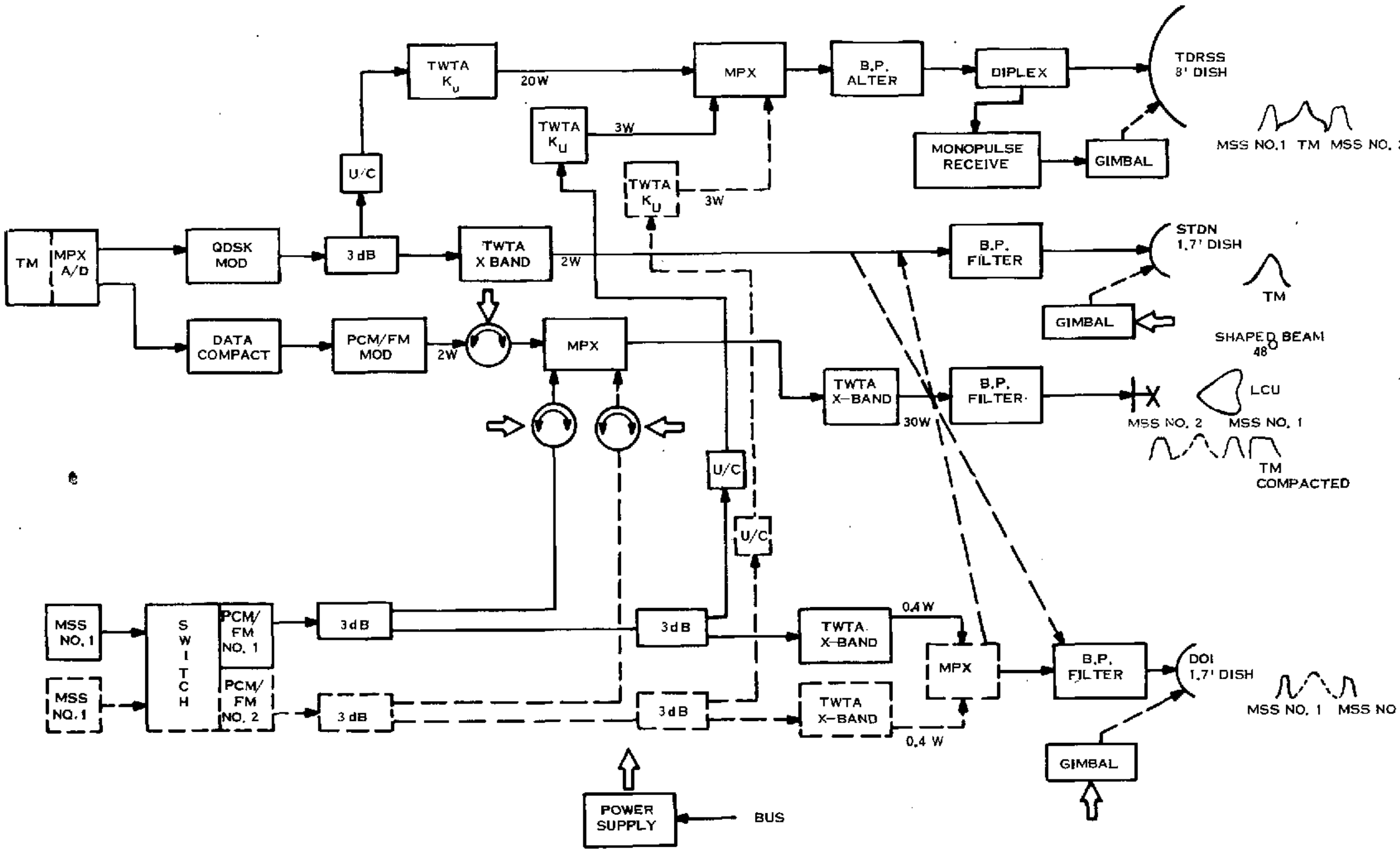

Figure 3-28. TDRSS
(TM + 1 MSS & TM + 2 MSS)

monitoring will provide fine pointing. The AGC is derived by measuring user signal strength during the programmed scan. A wide beam, carrier only, user beacon would probably be required. An alternate to the AGC monitored fine pointing would be monopulse tracking.

A number of alternates are available by which EOS acquires and tracks TDRSS. An antenna beam search by EOS could be used if the known TDRSS position does not preclude this. However, if a 0.5 degree beam at Ku-band and a 3.5 degree beam at S-band is assumed then open loop steering at Ku-band would appear difficult indeed, but could be achieved at S-band. One approach would be to acquire TDRSS at S-band and use monopulse for fine pointing. Another method would be to use a defocussing feed at Ku-band (which essentially broadens the beam) and thereby acquire and fine point at Ku-band. An error budget of open loop pointing variations will be required to finalize an approach.

Table 3-33 summarizes the relative cost, weight and power impacts for the alternatives considered relative to the baseline of a real time TM plus 1 MSS configuration. The WBVTR approach to global coverage is significantly heavier and demands more power than the TDRSS approach. Recurring costs are not significantly different, but development cost for TDRSS are much larger than the WBVTR approach. Further, there are far more development risks involved.

3.4.8 WIDEBAND DATA HANDLING/COMPACTION

The basic function of the wideband data system is to multiplex and digitize the analog sensor signals from the HRPI and the TM instruments. All the data will be serially transmitted over a wide band data link while about 1/8 of the data is selected dependent upon mode of operation, and sent via a narrow band data link to the Low Cost Users (LCU).

The baseline approach, as defined in the Radiation, Inc. study reports, was examined to determine the impact of changes to several of the significant system parameters used in those studies. The areas examined and the conclusions are summarized below:

Table 3-33. ROM WBVTR/TDRSS Relative Impact Summary

Configuration	Weight (pounds)	Power (watts)	Cost ($K) NR	R
TM + 1 MSS				
Real Time Only	REF	REF	REF	REF
Global (WBVTR's)	355	315	2020	1470
Global (TDRSS)	101	182	4960	1453
TM + 2 MSS				
Real Time Only	16	5	100	141
Global (WBVTR's)	448	306	2520	2021
Global (TDRSS)	130	107	4960	1754

Quantization. The impact of 6, 7, or 8 bit quantization was considered. Aside from the obvious 14% data rate/storage impact, which is estimated to change power and recurring cost by about the same percentage, no significant impact was found assuming the A/D conversion accuracy remained the same.

Sampling. Pixel oversampling in both the along scan and across scan direction were considered over the range from 1 to 1.6 samples per second. Results indicate a very significant cost, weight and power impact over this range. For example, a power increase from 30 to 50% and a cost and weight increase from 20 to 30% was the estimated impact of increasing the data rate due to an increase in in-track sampling from 1.0 to 1.6. Thus, justification for oversampling must be strongly substantiated. (Section addresses the overall system impact of sampling frequency).

Compactor Modes. Various compactor modes for both TM and HRPI were considered. Their impact can be considered by the type of compaction as follows:

Mode	TM	HRPI
Reduced Resolution	Minimum	Moderate, depending on design
Spectral Selection	Minimum	Minimum
Reduced Swath	Severe	N/A

The reduced resolution modes assume the reduction ratio to be an integral multiple of the number of detectors per band. Swath reduction always requires large memory irrespective of the type of scanner and thus impact is quite severe.

Integral Compactor. A design which integrates the compactor functions with the sampling, multiplexing and A/D functions was examined. (The Radiation, Inc. compactor study assumed all compactor functions to be separate and downstream of the serial 120 MBS data stream). Estimates indicate about a 50% reduction in total power (from 80 to about 40 watts) if the compactor design were integrated.

On-Board Correction. Various tradeoffs were considered for on-board vs. ground radiometric and geometric corrections for the various instruments. These have major impact on the baseline design and are discussed in Section 2 of this report.

Instrument/Wideband Data Handling Interface. The Radiation, Inc. baseline design provides for processing both instrument video data (via many analog lines) and instrument housekeeping telemetry data (bileval data), and merging these into a composite bit stream. The desired data, from a ground processing point of view, is "video" data with specific ancillary data. Some of this ancillary data will be derived from instrument housekeeping data; others will not. Thus, the recommended interface to both the Instruments and to the Wideband Data Handling Subsystem for housekeeping and ancillary data (serial digital commands) is the standard remote decoder/multiplexer.

3.5 POWER SUBSYSTEM DESIGN/COST TRADEOFFS

The major cost tradeoffs in the power subsystem area has been toward the evaluation and selection of the preferred subsystem approach from three candidates. Consideration has also been given to the selection of fixed vs. oriented and rigid vs. flexible solar arrays. In addition the subsystem approach for EOS-A was evaluated for follow on mission accommodation.

3.5.1 REQUIREMENTS AND ASSUMPTIONS

The power subsystem consists of the equipment housed in the Power Module plus the mission peculiar solar array and related drive and power transfer. Since two different types of implementation are being considered, the bus requirements of Table 3-34 are given for an unregulated supply and also for a regulated Direct Energy Transfer (DET) system.

A typical load power demand profile for the EOS-A mission was compiled and shown in Figure 3-29. The total daily experiment operating time was averaged over the number of orbits

Table 3-34. Power Subsystem Bus Voltage Characteristics

Parameter	For Unregulated Subsystem Implementation	For Regulated DET Subsystem Implementation
Voltage (nominal)	+ 28 vdc	+ 28 vdc
Regulation	$\pm$ 7 vdc max	$\pm$ 0.3 vdc (1 ampere to full load) including operating temperature and life.
Ripple	≤ 500 mv, peak-to-peak 5 Hz to 100 KHz	≤ 100 mv peak-to-peak
Line Drop	Not specified	Round trip from Power Module to using subsystem shall be ≤ 280 mv, except loads over 100 w shall be ≤ 500 mv.
Source Impedance	≤ 0.15 ohms, 1 Hz to 5 KHz ≤ 0.50 ohms, 5 KHz to 100 KHz ≤ 1.0 ohms, 100 KHz to 1 MHz	≤ 0.1 ohms, DC to 10 KHz
Normal Load Switching Transient	≤ $\pm$ 1 vdc for 100 ms or less	≤ $\pm$ 2 vdc with total energy ≤ 100 μ volt-sec
Power Regulator Failure Transient	Not specified	All subsystems shall be capable of surviving a bus voltage transient ≤ + 5 vdc with a total energy ≤ 100 μ volt-sec or ≤ -10 vdc with a total energy ≤ 250 μ volt-sec
Fault correction	All subsystems shall be capable of surviving a transient voltage drop to 20 volts or increase to 39 volts for ≤100 msec.	All subsystems shall be capable of surviving a transient voltage drop down to 15 vdc for ≤ 100 msec.

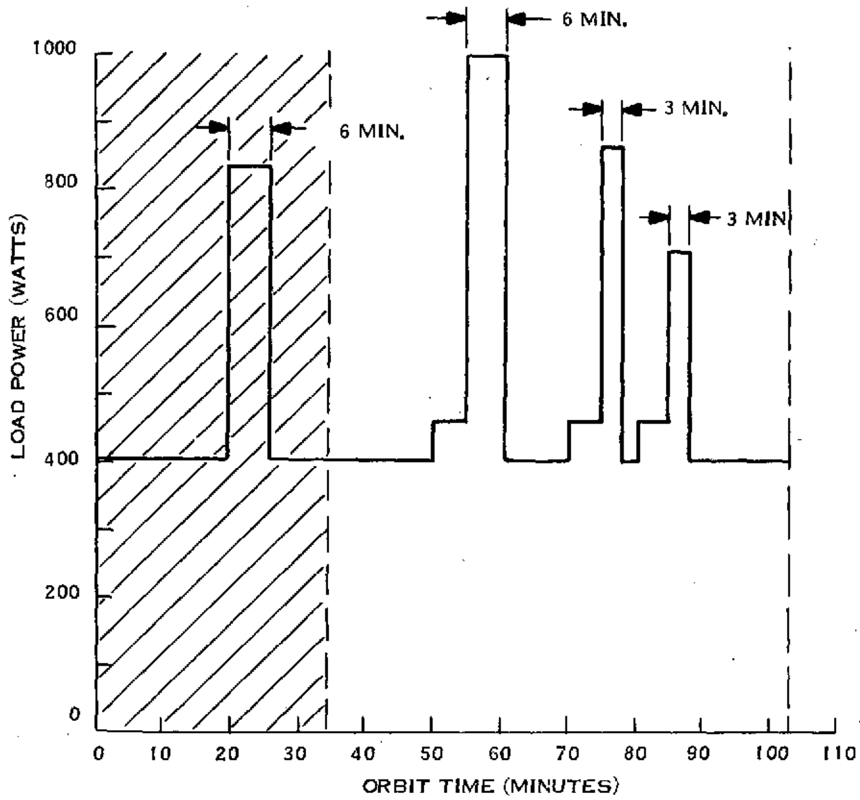

Figure 3-29. Load Power Profile for EOS-A

per day to yield a typical operational orbit. This orbit is divided into seven phases to accurately account for the peak load periods which may result in load share battery discharge during the daylight portion of the orbit. Table 3-35 summarizes these loads for a regulated bus implementation.

For an unregulated bus the load demands will be higher because of additional preregulation in the user loads. On an orbital average load basis the regulated bus approach is estimated to have 7 percent less demand.

3.5.2 ALTERNATIVE CONSIDERED

Baseline Design. The Baseline design uses the basic OAO-C power subsystem components which include the Power Regulation Unit, Power Control Unit, Diode Box and Battery. Figure 3-30 shows a simplified functional block diagram of this approach.

Table 3-35. EOS-A Load Power Demand for Regulated Supply Voltage

Operational Mode / Subsystem	Launch	Operational Average Base Load	WBTVR Playback (6 min)	WBVTR Record & Real Time to Low Cost Users (6 min)	Real Time Data Read-out to Ground Stations and to Low Cost Users (3 min)	Sensor Warm-up (15 min)	Real Time Data Read-out to Low Cost Users (3 min)
Attitude Control	80.	118.	118.	118.	118.	118.	118.
C&DH	105.	120.	120.	120.	120.	120.	120.
SCCM	5.	85.	85.	85.	85.	85.	85.
Reaction Control	-	20.	20.	20.	20.	20.	20.
W/B Comm	-	-	473.	464.	330.	12.	255.
Experiments	21.	37.	37.	210.	210.	132.	132.
Subtotal	211.	380.	803.	967.	833.	473.	680.
Distribution Losses	4.	8.	16.	19.	17.	9.	14.
Power Module	15.	15.	15.	15.	15.	15.	15.
Total	230.	403.	834.	1001.	865.	461.	709.

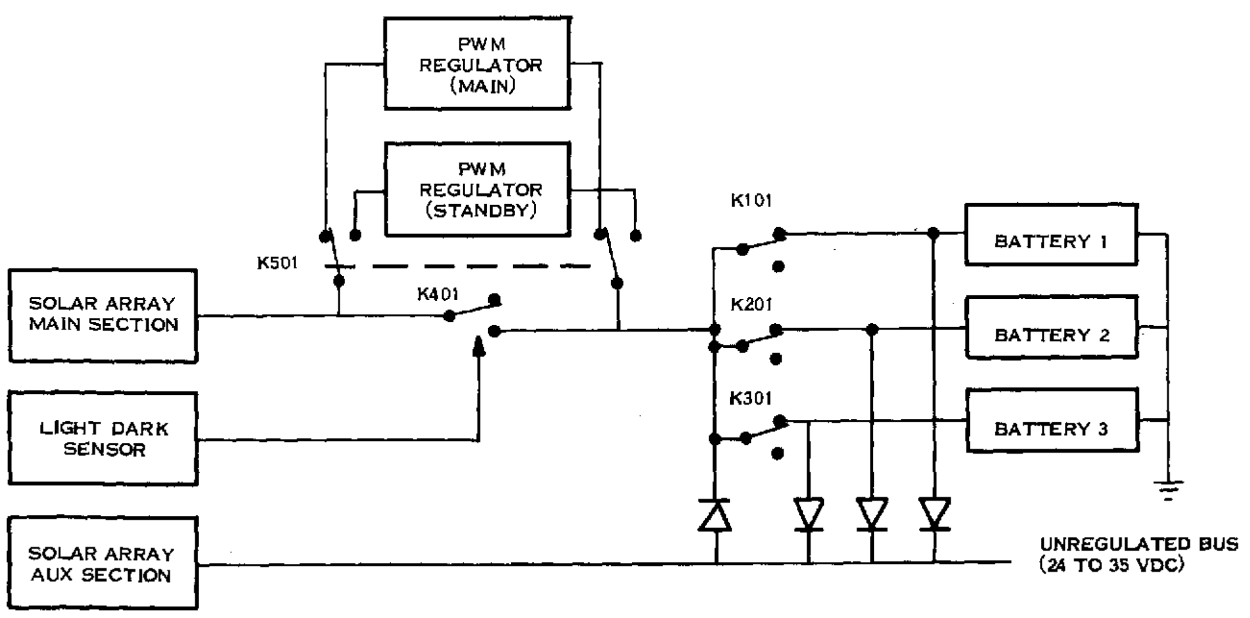

Figure 3-30. Simplified Functional Block Diagram of Baseline Design Approach

Optimization of Baseline Design. Possible improvements to the Baseline Design have been explored with the objective of increasing overall reliability and reducing cost. Figure 3-31 shows one such change to the Baseline which provides positive control of battery charge by the use of individual PWM buck battery charge regulators. Each battery is individually controlled to the temperature-compensated voltage limit which is selected by command. Also the K401 "Shunt/Regulate" switch function is eliminated by making the battery charge regulators with a 100 percent on, low drop pass state (Q1 full on and saturated when no bucking is required). The unreliability of the K401 relay as well as the Light/Dark sensor interface is thus eliminated.

External PWM duty cycle control permits operation near the maximum power point by regulating the input current to a commanded level which corresponds to the current required to obtain nearly maximum power from the main solar array over the expected temperature range.

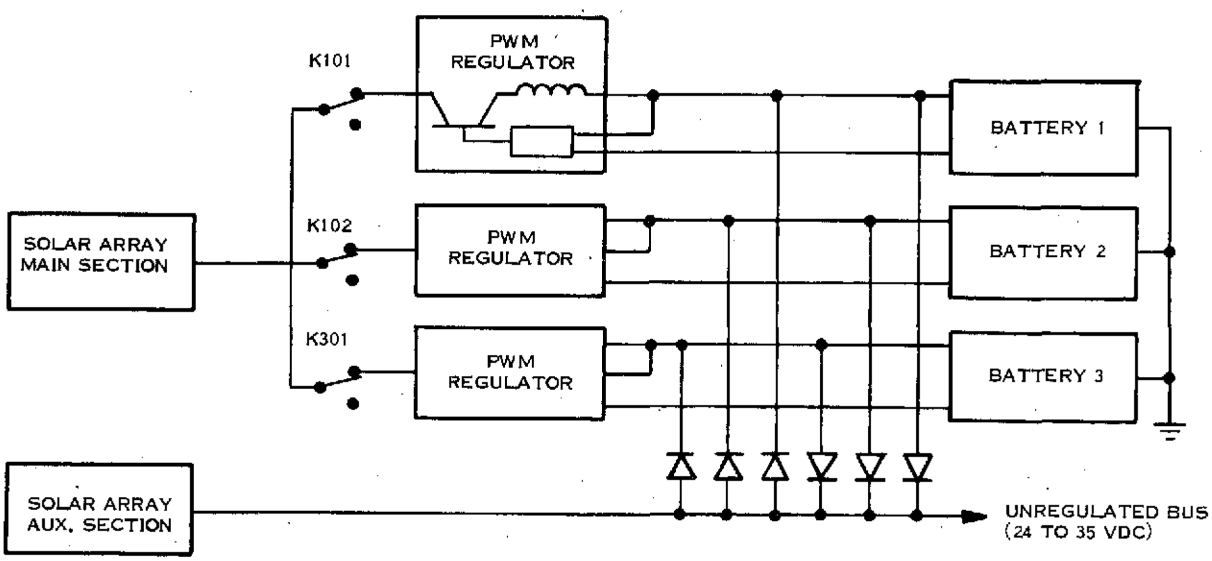

Figure 3-31. Individual Battery Charge Regulators for the Baseline Design

Further changes to the Power Module which reduce the number of different components are: (1) to locate the discharge isolation diodes in the individual battery PWM regulators, thus eliminating a separate component called a "Diode Box"; (2) include the dc-to-dc conversion functions of the Signal Conditioning Assembly in the PWM battery charge regulators since the oscillator is already there and eliminate the Signal Conditioning Assembly by the integration of its remaining functions with other components; and (3) combine the Bus Protection Assembly and the Power Disconnect and Current Sensor Assembly into one box for a net reduction in fabrication and test cost.

DET Alternate Design. A simplified functional block diagram for the regulated Direct Energy Transfer (DET) implementation is shown in Figure 3-32. This power subsystem provides a regulated bus (+28 $\pm$ 0.3 vdc) for distribution to the user subsystems and experiments. The bus voltage regulation is obtained without the use of an in-line regulator. The Central Control Unit senses the bus voltage level and controls the operation of the battery discharge boost converters, battery charge regulators and sequenced partial shunt regulator. The Power Regulation Unit (PRU) contains the charge/discharge electronics which are associated with each battery. There is one PRU for every battery in the subsystem. It consists of a PWM buck battery charge regulator and a discharge boost converter. The charge regulator is dedicated to the associated battery, but the boost converter in each PRU receives discharge current from all batteries. An individual boost converter output rating of 500 watts was selected for the EOS type missions. With this rated output power, three PRU's for the EOS-A mission will allow operation of the experiments in the event of a single boost converter failure. The PRU also contains the battery discharge isolation diodes, charge disable relay and battery reconditioning circuitry (if required). The PWM buck battery charge regulators provide charge limiting at 7.0 amperes per battery and voltage limiting at one of four ground commandable, temperature compensated levels.

During excess power conditions, bus regulation is maintained by a sequenced partial shunt regulator. The dissipative elements of this regulator are contained in a shunt load panel which is shown located on the array side of the slip rings.

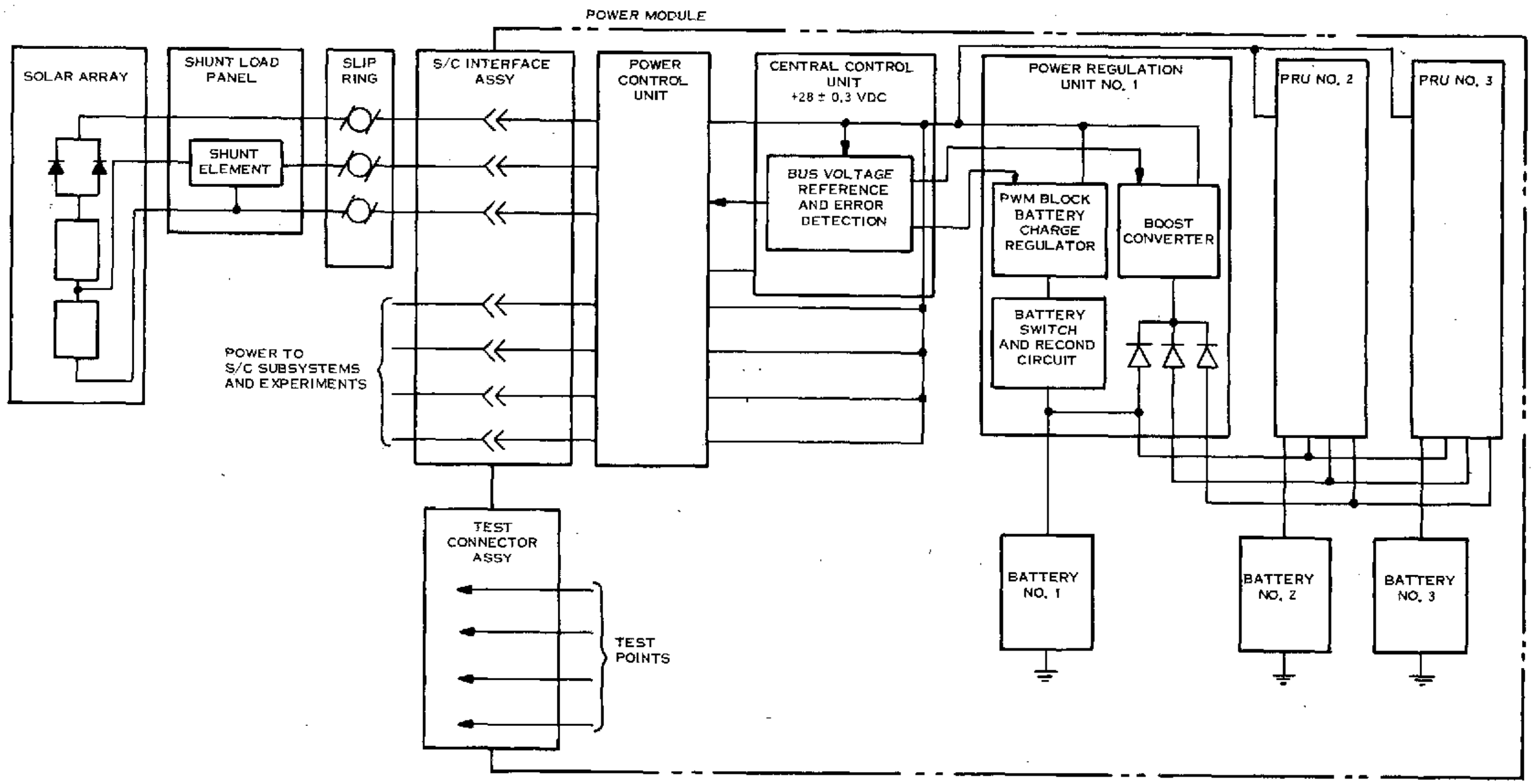

Figure 3-32. Simplified Functional Block Diagram of DET Design Approach

Table 3-36 gives the calculated size and weight of the components for the DET power subsystem.

Table 3-36. Component Size and Weight Summary for DET Approach

Component	Quantity Per Spacecraft	Unit Size LxWxH	Total Weight (lb)
Central Control Unit	1	4"x5"x4"	4.
Power Regulation Unit	3	11"x6"x6"	45.
Battery	3	8"x10"x7.8"	141.
Power Control Unit	1	21"x10"x4"	30.
Remote Decoder	2	4"x3.6"x1.3"	2.
Remote Mux	2	4"x3.6"x1.3"	2.
Spacecraft Interface Assembly	1	10.5"x10"x7"	15.
Test Connector Assembly	1	10"x8"x3"	5.
Shunt Load Panel *	1		6.
Total Weight for Power Subsystem (less Solar Array)			250.

* The Shunt Load Panel is located external to the Power Module and is mission peculiar associated with the solar array size.

3.5.3 PERFORMANCE ANALYSIS

A digital simulation program was developed to analyze the performance of both the Baseline and the DET Alternate Designs. In each case this program permits an accurate simulation of the actual operation of the power subsystem under a given set of load conditions. The simulation was run for end-of-mission (EOM) conditions at the aphelion solar intensity. The summary results for both implementation approaches is given in Table 3-37.

Table 3-37. Performance Comparison for EOS-A Mission Baseline and DET Alternate

Performance Parameter	Baseline	Alternate
Solar Array Panel Area-m^2 (ft^2)	10.50 (113)	9.85 (100)
Number of Cells (2x4 cm)	11280.	10608.
Orbital Average Load Power (Watts)	529.	494.
Total Discharge (Watt-minutes)	19598.	19876.
Total Charge (Watt-minutes)	22178.	21860.
Load Share Discharge (Watt-minutes)	1523.	686.
Eclipse Discharge (Watt-minutes)	18075.	19190.
Total Subsystem Losses (Watt-minutes)	1458.	7069.

This comparative analysis leads to the conclusion that the overall energy utilization effectiveness is about equal for either implementation approach. The greater internal losses for the DET Alternate are compensated by improved utilization of solar array power. The net result is that the DET Alternate requires seven percent less solar array area which reflects the correspondingly lower orbital average load power demand associated with the regulated supply voltage.

3.5.4 COST COMPARISON

A comparison of power subsystem costs was performed to assess the difference between the basic Baseline approach, the optimized Baseline and the DET alternate. Both non-recurring and unit recurring costs were considered. The solar array unit recurring cost is based on a cost of \$43,000 m^2(\$4000 ft^2). For the Baseline approach the unit recurring cost of the OAO equipment was obtained from GSFC*.

A graphical comparison of the cost analysis on a unit subsystem basis is given in Figure 3-33. Based on those results the Baseline approach is shown to produce lower total cost if the number

* Telephone communication with C. W. Hoffman, May 28, 1974.

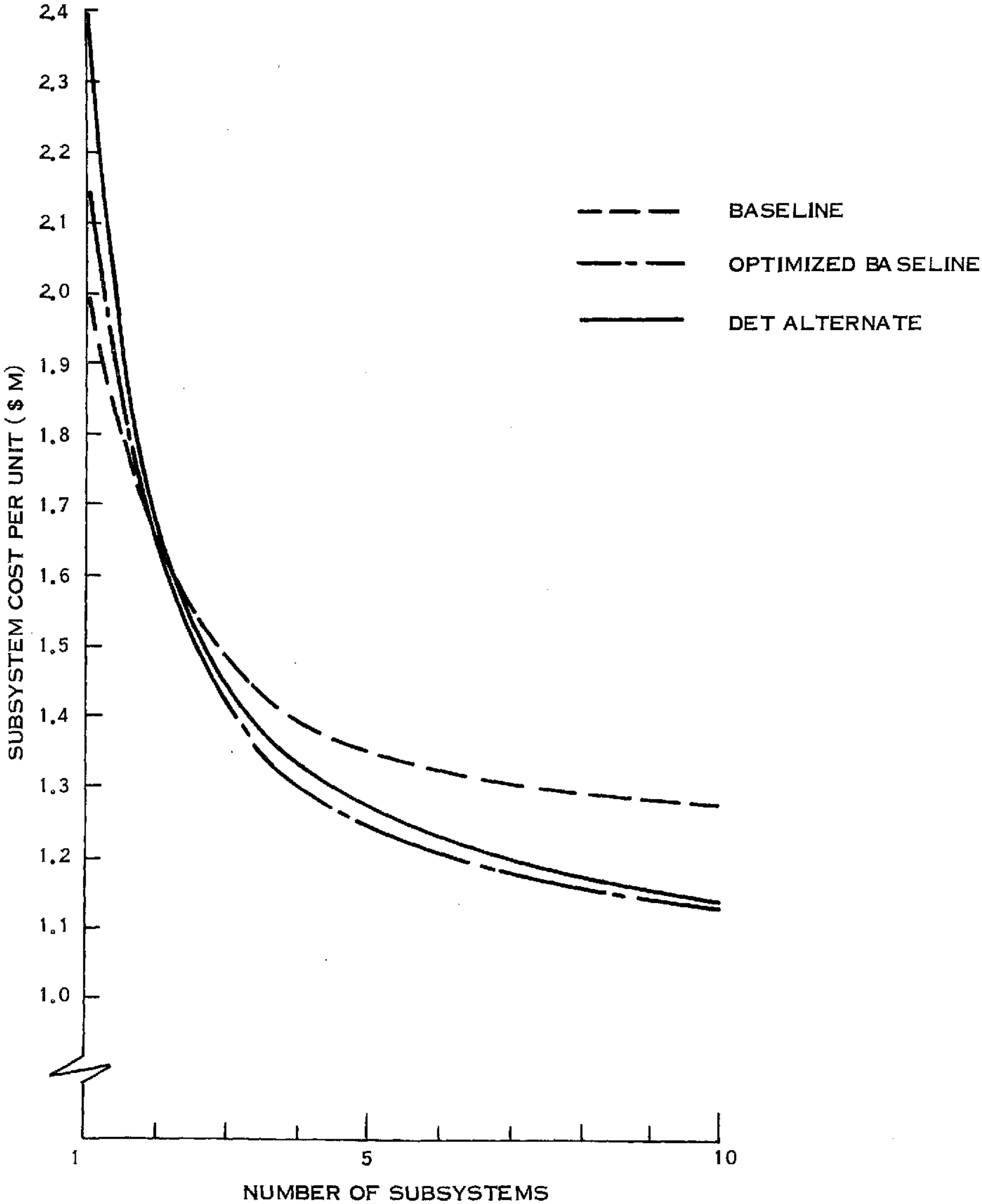

Figure 3-33. Cost Comparison of Baseline and Alternate Power Subsystems

of subsystems required for EOS missions is less than two or three. Above this level the unit recurring cost savings associated with either the DET Alternate approach or the optimized Baseline are more than enough to counteract the higher non-recurring cost associated with either of these alternate designs.

3.5.5 SUBSYSTEM SELECTION

The optimized Baseline approach and the DET Alternate have been shown to have virtually identical unit subsystem recurring costs. In either case this is some $180K per subsystem lower than the original Baseline. The major difference between these two alternative implementation approaches is the regulation of the distributed bus voltage. The optimized Baseline provides the same unregulated (+28 $\pm$ 4 vdc nominal range) bus voltage as the original Baseline. On the other hand, the DET Alternate provides a regulated (+28 $\pm$ 0.3 vdc) bus voltage. The regulated supply voltage results in other inherent total system cost savings which are not reflected in the power subsystem costs. These include: (1) reduced equipment costs in user subsystems and experiments due to the elimination of the regulation and pre-regulation functions within each subsystem and/or component, and (2) reduced system and subsystem integration and test costs due to the elimination of wide input voltage variations as a test parameter. These cost saving factors associated with a regulated bus voltage are difficult to evaluate quantitively, but examples can be cited to demonstrate that these potential savings are real. One such example is the WBVTR which is currently being designed to operate with a regulated input voltage of +28 $\pm$ 0.5 vdc. For an unregulated supply voltage, the WBVTR input voltage must be regulated by a device housed within the W/B communications module.

The virtually identical power subsystem costs coupled with the real potential for other total system cost savings have led to the selection of the DET Alternate approach which supplies a regulated bus voltage.

3.5.6 ORIENTED VS. FIXED SOLAR ARRAY TRADE STUDY

A performance/cost trade study of a fixed solar array verses the baseline oriented solar array was performed for the nominal EOS-A orbit. Figure 3-34 shows the fixed array geometry which was assumed to be equally distributed between surfaces A_1, A_2 and A_3 with tilt angle of

30 degrees. Previous studies of this nature have shown this angle to be a reasonable compromise between terminator power capability and subsolar point power capability.

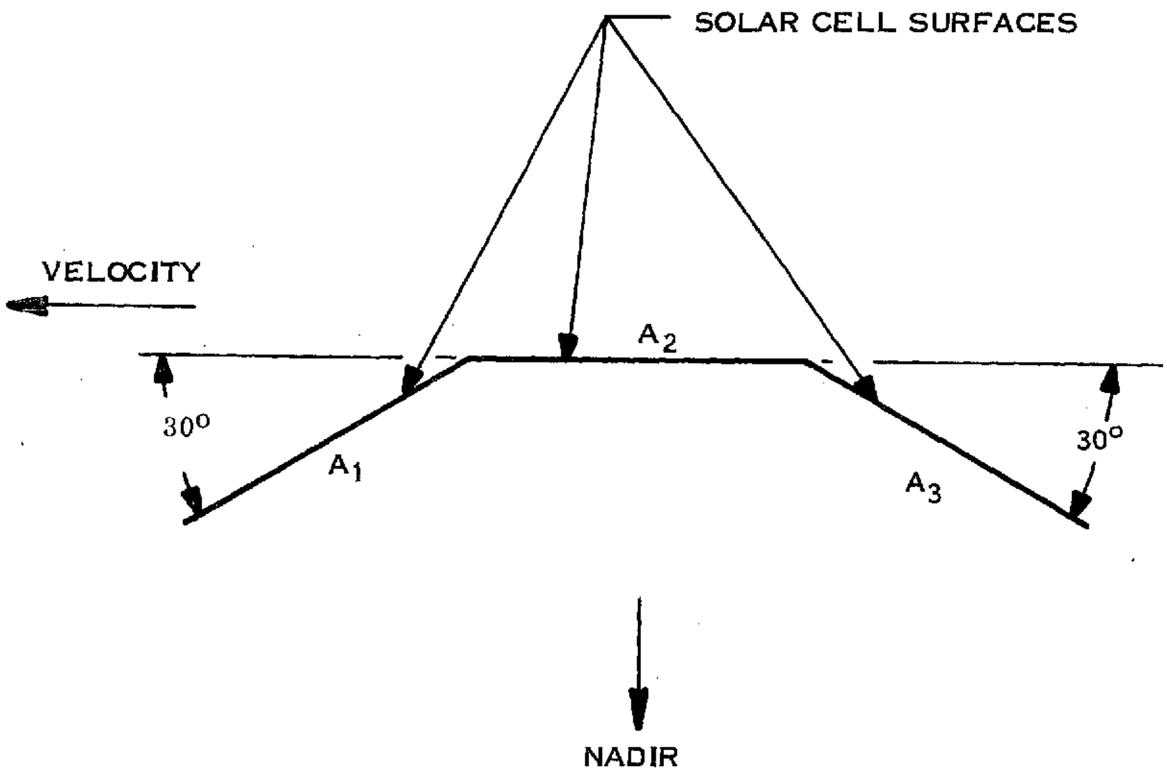

Figure 3-34. Fixed Solar Array Panel Configuration

Table 3-38 shows the comparative subsystem requirements and costs for the EOS-A load profile. The fixed array geometry causes load sharing to occur both prior to and following the spacecraft night/day transition. The high solar array output capability at the subsolar point necessiated the addition of one battery with associated PRU. The total compliment of four batteries provides sufficient recharge capability if the charge rate limit is set at 13 amperes per battery. This limit corresponds to the C/1.85 rate which will necessiate the use of recombination electrodes in the battery cells.

The fixed array approach is estimated to cost \$382.K more per spacecraft than an equivalent oriented array system and is not recommended.

Table 3-38. Comparison of Fixed vs. Oriented Solar Arrays for EOS-A

	Oriented Solar Array (Baseline)	Fixed Solar Array
Solar Array Panel Area (m^2)	9.85	21.74
(ft^2)	106.	234.
Number of Batteries/PRU's	3.	4.
Recurring Solar Array Cost ($K)	424.	936.
Recurring Solar Array Drive Cost ($K)	200.	--
Recurring Cost of one PRU + one Battery ($K)	—	70.
Total Recurring Cost per Spacecraft ($K)	624.	1006.

3.5.7 RIGID VS FLEXIBLE SOLAR ARRAY TRADE STUDY

Within the last decade several flexible solar array designs have been developed in the USA, Canada, and the United Kingdom. These designs have been of two basic types: (1) cylindrical roll-up and (2) accordian folded flat-pack. In October 1971 an experimental roll-up array built by Hughes, was launched into low earth orbit. The solar array portion of this system, called FRUSA, performed satisfactorily and demonstrated that a roll-up array could be deployed, extended and retracted in-orbit. A flexible accordian folded flat-pack array is currently being qualified for flight on the Canadian Communications Technology Satellite (CTS) which is scheduled for launch in 1975. There is little doubt that either flexible array approach could meet the EOS mission requirements with less weight and lower stowed volume when compared to a folding rigid panel array. The roll-up array approach has the additional advantage of being inherently retractable. On-orbit retractability requires special design solutions for both the folding rigid panel array and the accordian folded flat-pack.

The major disadvantage of the roll-up array is the higher unit recurring cost. It is estimated that a flexible roll-up array will have approximately 25 percent higher recurring cost when compared to an equivalent rigid folding panel design. Furhter, the confidence in being able to meet these costs because of development and production uncertainties is low. The folding rigid panel array is therefore recommended for EOS-A.

3.5.8 FOLLOW-ON INSTRUMENT ACCOMMODATION

The ability of the power subsystem to adapt to the load requirements of follow-on instruments and alternate missions was assessed for both the Baseline design and the DET Alternate design. The Synthetic Aperture Radar (SAR) mission was elected for detailed analysis because it represents the maximum load demand of any of the EOS class missions, both in terms of peak load (above 2 kW) and orbital average load demand. The instrument compliment for the mission was assumed to be the SAR and a Thematic Mapper. Table 3-39 summarizes the load demand for this mission with a regulated supply voltage. The corresponding load demand for an unregulated supply voltage was obtained by maintaining the same ratio of unregulated demand-to-regulated demand at 28 vdc as was obtained for the EOS-A mission.

Table 3-39. SAR Mission Load Power Demand for Regulated Supply Voltage

Load Power Demand (Watts)

Subsystem / Operational Mode	Operational Average Baseload	SAR Warm-up (5 min)	SAR Night Operation (3 min)	WBVTR Playback (6 min)	WBVTR Record + Real Time to Low Cost Users (6 min)	Real Time Data Read-out to Ground Stations and to Low Cost Users (6 min)	Sensor Warm-up (15 min)	Real Time Read-out to Low Cost Users (3 min)
Attitude Control	118.	118.	118.	118.	118.	118.	118.	118.
C&DH	120.	120.	120.	120.	120.	120.	120.	120.
SCCM	85.	35.	35.	35.	35.	35.	35.	35.
Reaction Control	20.	20.	20.	20.	20.	20.	20.	20.
W/B Comm	--	--	330.	473.	464.	330.	12.	255.
Experiments	17.	57.	1304.	17.	1510.	1510.	112.	112.
Subtotal	360.	400.	1927.	783.	2267.	2133.	417.	660.
Distribution Losses	7.	8.	39.	16.	45.	43.	8.	13.
Power Module	15.	15.	15.	15.	15.	15.	15.	15.
Total	382.	423.	1981.	814.	2327.	2191.	440.	688.

The performance of both subsystem approaches was analysed with the aid of the associated digital simulation program. The results of this analyses are summarized in Table 3-40. The Baseline approach was shown to require four batteries (22 cells, 24 A-H each). This battery compliment will require a redesign of the basic OAO battery module for the Baseline approach. The DET Alternate approach requires the addition of two batteries and two PRU's (five total) but these units are identical to those used on other EOS missions. The required addition of boost converters, with associated standby power loss and lower total operating efficiency, resulted in less overall power conversion efficiency for the DET Alternate. As a result the DET Alternate is shown to require slightly higher solar array area when compared to the Baseline.

Table 3-40. Summary Power Subsystem Analysis for SAR Mission

Performance Parameter	Baseline	DET Alternate
Bus Voltage (vdc)	28 ± 7	28 ± 0.3
Orbital Average Load Power (Watts)	683.	639.
Peak Load Power (Watts)	2463.	2327.
Number of Batteries	4 (1)	5 (2)
Total Battery Weight (lbs)	235.	235.
Solar Array Area (ft^2)	147.	148.
Number of Different Components in Power Subsystem (exclusive of solar array and drive)	12	9
Number of Boxes in Power Subsystem	18	19
Non-Recurring Costs (3)	\$ 324 K	\$ 310 K
Recurring Cost per Subsystem	1333 K	1302 K
Total Cost for One Subsystem	\$ 1657 K	\$ 1612 K

Notes:

(1) Four 22 cell, 24 A-H batteries, individually packaged.

(2) Five 17 cell, 24 A-H batteries, individually packaged.

(3) Assumes SAR is one of five subsystems.

The cost comparison of the two approaches is for delivery of one subsystem for the SAR mission which is one of five EOS type power subsystems. The resulting total unit power subsystem cost for the SAR mission is virtually identical with either approach.

In summary, both approaches are comparable in both performance and cost for the SAR mission. For other missions where load demands are more representative of the EOS-A requirements, the DET approach offers a cost advantage.

3.6 ATTITUDE CONTROL SUBSYSTEM DESIGN/COST TRADEOFFS

3.6.1 REQUIREMENTS AND APPROACH

The Attitude Control Subsystem requirements in the GSFC specification are summarized in Table 3-41. The mission rate requirements are specified for a fixed time interval (30 minutes) and can therefore be interpreted as a position change over the same time interval. This interpretation is shown in Figure 3-35.

The EOS-A ACS requirements, as determined by systems analysis and based upon payload requirements, are summarized graphically in Figure 3-36. The position requirement is more restrictive than the GSFC requirement, and is not the same on all axes. The rate requirement is similar to the GSFC requirement, except at the high frequency end.

In performing cost trades, primary attention has been given to earth oriented mission, particularly EOS-A. These missions have been selected as the "baseline" since they typically impose the severest tasks, and most of the missions under consideration are earth oriented. The nature of the analysis, however, makes most of the results directly applicable to inertial missions,which have the same attitude requirements.

In developing the ACS design, extensive use has been made of the on-board computer. This approach has been selected not only to maximize system flexibility, but to develop a cost effective Attitude Control Subsystem.

3.6.2 ALTERNATE DESIGN CONSIDERATIONS

GSFC Baseline. The GSFC baseline ACS, as provided in the specification, is shown in Figure 3-37. The ACS contains an inertial reference unit (IRU) for rate control and attitude estimation, a star tracker for attitude determination and IRU update, and sun sensors (fine and coarse) for acquisition and reacquisition. The primary actuators for fine control are momemtun wheels, with coarse jets for coarse control and acquisition and reacquisition.

Table 3-41. ACS Requirements Goddard Specification

Mission Types	Attitude (All Axes)	Rate/Time (All Axes)	Jitter/Time (All Axes)	Comments
Earth Oriented	$\pm .01^\circ$	$\pm 10^{-6}$ °/sec/30 min.	$\pm .0003^\circ$/30 sec $\pm .0006^\circ$/20 min	
Inertial	$\pm .01^\circ$	$\pm 10^{-6}$ °/sec/30 min.	$\pm .0006^\circ$	Jitter is relative to average rate
Stellar Payload	$\pm 3.10^{-6}$°		$\pm 10^{-7}$ deg	Jitter is relative to average rate. Attitude excludes sensor error.
Operating Modes				
Acquisition	$\pm 2^\circ$	$\pm .03^\circ$/sec		Requirements are from initial values of 1 °/sec and random initial attitude
Inertial Hold		$\pm .003^\circ$/hr		$.03^\circ$/hr prior to in-orbit calibration
Coarse Hold	$\pm 7^\circ$	$\pm .05^\circ$		Attitude is total attitude error to sun. 30 day life requirement.
Slew	$\pm .03^\circ$	2°/min		Rate is a slew capability. Position is accuracy after a 90° rotation.

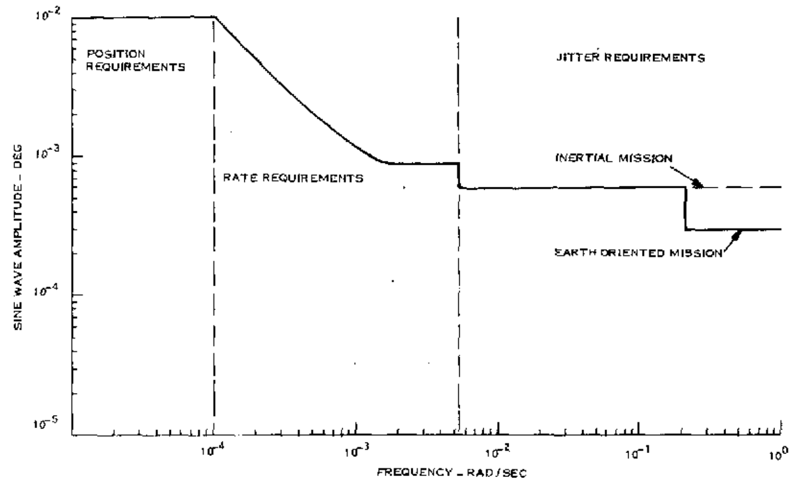

Figure 3-35. Spacecraft Attitude Requirements

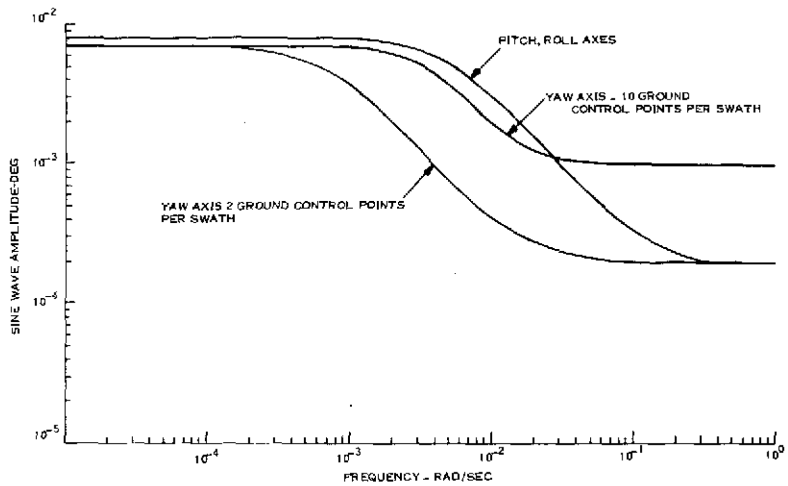

Figure 3-36. Spacecraft Attitude Requirements

The primary actuators for fine control are momentum wheels, with coarse jets for coarse control and acquisition/reacquisition. Momentum wheel unloading is normally accomplished by magnetic coils in conjunction with a magnetometer. The fine jet reaction control subsystem is provided for backup momentum unloading. Acquisition is accomplished by using the coarse sun sensor and the digital sun sensor. The solar aspect sensor assists in attitude determination by the ground control center.

Optimized Baseline. The GSFC baseline contains more than the essential hardware elements to perform the required mission. From a cost effectiveness standpoint, therefore, hardware simplification is required. Figure 3-38 shows the ACS baseline reduced to its simplest hardware form.

3.6.3 COST/PERFORMANCE TRADE STUDIES

To facilitate the discussion of the cost/performance trades, each component within the GSFC baseline, its primary, backup functions, and possible alternatives were tabulated (Table 3-42). It is evident from this table that the cost/performance trades are not possible in all areas.

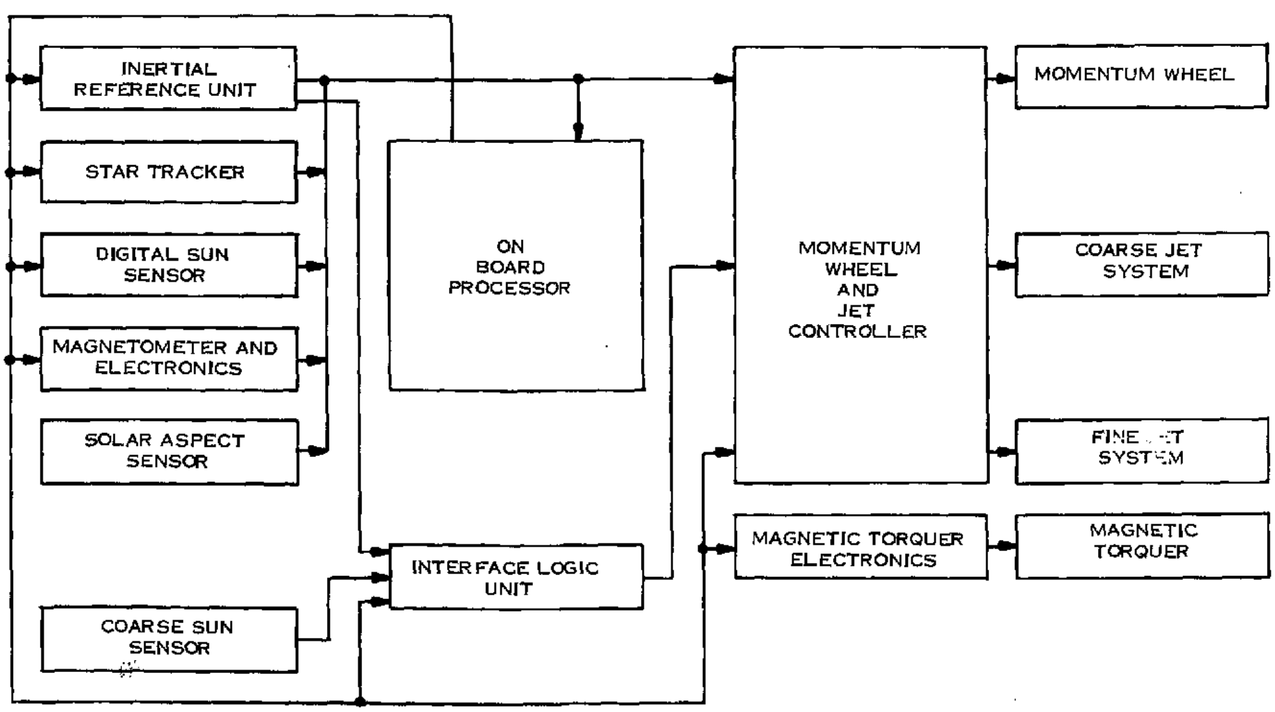

Figure 3-37. GSFC ACS Baseline

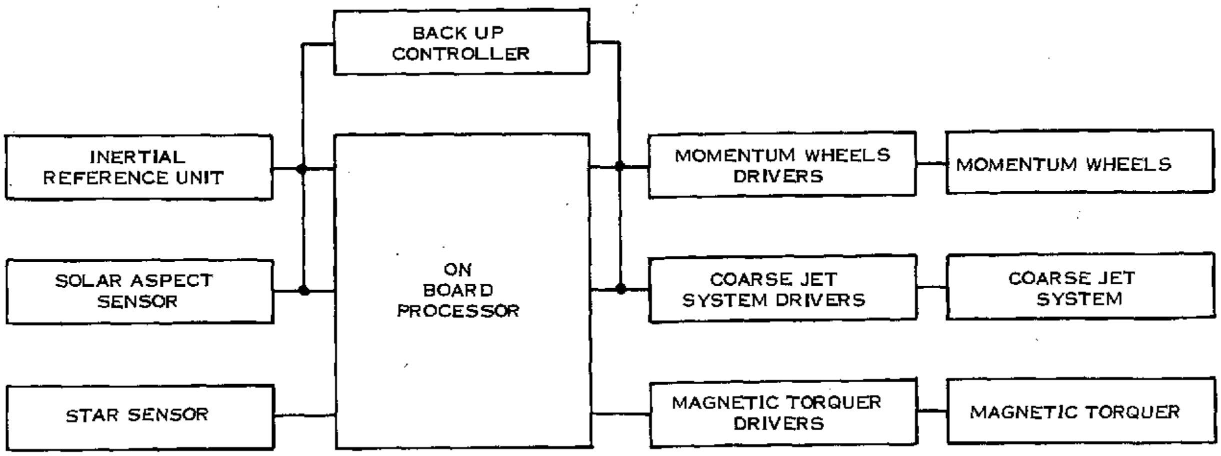

Figure 3-38. Optimized Baseline
(Minimum Hardware Configuration)

The areas in which tradeoffs are possible are: the inertial reference unit, the star tracker, coarse sun sensors, fine sun sensors, the magnetometer, and the fine reaction control subsystem. The first two are of considerable importance because of their high cost.

3.6.4 STAR SENSOR TRADE STUDIES

Several types of star sensors are traded:

- o Fixed head star tracker (baseline)
- o Star crossing detector
- o Gimballed Star Tracker
- o Single axis tracker

Table 3-43 consolidates the characteristics of most of the star sensors which are applicable. The chart is divided into four major categories: Physical Characteristics, Performance Characteristics, Adaptability, and Cost.

Table 3-42. Component Alternatives

Component	Prime Function	Back-up Function	Approach Alternatives	Comments
Inertial Ref. Unit	Rate Sensing Position Update	None	Single degree of freedom gyros Double degree of freedom gyros	-
Star Tracker	Star Sensing IRU Update	None	Star Crossing Detector Gimballed Star Tracker	-
Coarse Sun Sensor	Acquisition Reacquisition	Coarse Control Mode	Magnetometer Software	-
Fine Sun Sensor	Acquisition	----	Coarse Sun Sensor/Software	-
Magnetometer	Acquisition Reacquisition Momentum Unload Att. Determination	----	Software	-
Momentum Wheel	Fine Control	----	None	Control Moment Gyro viable for Large Spacecraft
Coarse Reaction Control Subsystem	Acquisition Boost/OA Control	None	None	-
Fine Reaction Control Subsystem	Backup Momentum Unload		Coarse RCS Software	-
Magnetic Torquers	Momentum Unload	None	None	Backed up by Fine Reaction Control Subsystem
On-board Computer (Software)	ACS Control	----	----	Backed up by Coarse Mode
Solar Aspect Sensor	Attitude Determination on Ground	None	None	-

Performance Characteristics. The performance characteristics are the most significant for evaluation purposes. In evaluating the star sensors for the missions under consideration, operating field of view, sensitivity, and accuracy must be considered simultaneously. One of the significant differences is in the detector type. Two types of detectors are shown: a silicon photovoltaic detector, and an S-20 photomultiplier. The two detector types will not detect the same stars with the same sensitivities, and the effect of the difference is particularly evident when the time between star updates is calculated. An update analysis, performed for a silicon detector with a sensitivity to 3.65 star magnitude, and an $8^{\circ} \times 8^{\circ}$ field of view, indicated that nearly 87 percent of the maximum times between updates were less than 1000 seconds (for the nominal EOS-A orbit). An analysis identical to the one above, performed using an S-20 detector, indicated that 87 percent of the maximum times between updates were 2580 seconds, 1580 seconds higher than with silicon. The longer time interval is a direct result of sensor type, and distribution of stars.

Star catalogs indicate that there are more than twice as many bright "Silicon" stars as "S-20" stars. As a consequence, to obtain the same number of star updates, a star sensor using an S-20 detector must have a higher sensitivity than one using a Silicon detector. Preliminary analyses have indicated that for proper ACS operation, the S-20 type star sensor should have a star magnitude capability of approximately 4.5, one magnitude more sensitive than the silicon detectors. Referring to Table 3-43, only two fixed head star trackers (in their off-the-shelf configuration) have sensitivities of the proper order. A redesign or modification to the existing designs may improve the sensitivity of the other trackers, but would have to be evaluated on an individual component basis, since the modification may be extensive (optical redesign for example). Star trackers do, however, have a slight advantage over star crossing detectors in that they provide information of the star for as long as the star is within the field of view. This is approximately eight degrees, and therefore, the angular separation of the star updates is reduced by eight degrees.

Table 3-43. Star Sensor Data

Candidate	Physical Characteristics			Perform. Characteristics				Adaptability					Cost	
	Volume in^3	Weight lb	Power Watts	Operating Field of View	Sensitivity Mag	Det.	Accuracy	EOS	SEOS	Seasat	SMM	Inertial	Non-Recurr.	Recurr.
Star Crossing Detectors														
One	79*	4.7*	1.5	10°	3.65	Si	6 sec Bias	Yes	Partial	Yes	No	No	275,000	80,000
Two	180*	3*	.5	9.1°	2.5	Si	4 sec Bias	No	No	Yes	No	No	271,000	72,000
Fixed Head Star Tracker														
One	766*	23*	7.7	3° dia.	6	S20	2 sec null	No	No	No	Yes	Yes		
Two	206*	9.5*	8.5	8° dia.	3	S20	12 sec null	No	No	Yes	Yes	Yes		
Three	279*	6*	5.0	$8^{\circ} \times 8^{\circ}$	3	S20	60 sec null	No	No	Yes	Yes	Yes		
Four				$10^{\circ} \times 10^{\circ}$	4.5	S20	30 sec null	Yes	Partial	Yes	Yes	Yes	769,000 Developmental	100,000
Five	352*	16*	7.1	$8^{\circ} \times 8^{\circ}$	4	S20	10 sec null	Yes	Partial	Yes	Yes	Yes		
Six	378*	11*	5	$8^{\circ} \times 8^{\circ}$	6	S20	10 sec null	Yes	Partial	Yes	Yes	Yes	311,000	92,000
Gimballed Star Trackers														
One				$60^{\circ} \times 60^{\circ}$	2.8	S20	22 sec null	Yes	Yes	Yes	Yes	Yes		
Single Axis Tracker														
One	264*	7*	3.5	$16^{\circ} \times 18.2^{\circ}$	2	S20	15 sec null	Yes	Yes	Yes	Yes	Yes		
Two	330*	11*	6.0	$4^{\circ} \times 86^{\circ}$	3	Si	60 sec	No	No	Yes	Yes	Yes	521,000	303,000

* Excluding Sun Shield

For a gimballed star tracker, the difference in sensitivity/detector is much less significant since the tracker can follow a particular star for an extended period. Large angular travels can be reduced by changing the orientation of the tracking element with respect to the orbit plane. Factoring accuracy into the evaluation, the star crossing detector is more accurate than most of the star trackers. The data supplied by the crossing detectors is different from that supplied by the star tracker, but the use of multiple slits permits the crossing detector to provide two axis information. As a consequence, the accuracies are comparable for the purposes of the evaluation. The degradation in accuracy associated with the off-null readings for the fixed head star trackers has been ignored by assuming suitable calibration.

Adaptability. There are five basic missions which the ACS is required to support: EOS, SEOS, Solar Max, Seasat, and an Inertial Mission (per GSFC/ACS specification).

From the previous discussion, it is obvious that the Star Crossing Detector, and the gimballed Star Tracker, are compatible with EOS. The Single Axis Trackers do not have the proper combination of field of view, sensitivity and accuracy. Only number 6 (Table 3-43) of the fixed head star trackers is acceptable. The first star tracker has excellent accuracy, but the small field of view makes acquisition difficult, and the high sensitivity makes star recognition difficult in normal operations.

A single star crossing detector is not a practical approach for SEOS unless more expensive (third generation) gyros are used. Multiple star crossing detectors do appear feasible, however. A fixed head star tracker makes an excellent Polaris Tracker, and is readily adaptable to SEOS. However, more than one must be used to obtain adequate pitch information.

The gimballed star trackers, and single axis trackers are completely adaptable.

The relatively large pointing requirements (0.2 to 0.5 degrees) of SEASAT allows any of the star sensors to be used. Number on fixed head tracker is not recommended, however, because of its small field of view.

Solar Maximum Mission is nearly an inertial mission, and the stars will cross the sensor slowly if at all. As a consequence star crossing detectors are not adaptable. Fixed Head Star Trackers, Gimballed Star Trackers and Single Axis Trackers are acceptable.

Cost. The cost of the star sensors are shown for all four star sensor types. For all but the gimballed star tracker, the cost figures represent vendor quotes. The gimballed star tracker cost is an estimate.

Conclusions. The gimballed star tracker represents the most versatile component for all the missions, but it is also the heaviest, bulkiest, most complex, and most expensive. As a consequence, it is not considered a reasonable candidate.

Single axis trackers have also been eliminated, based primarily on cost and limited sensitivity. Of the two remaining types, the fixed head star tracker has the highest weight, power and volume, but is the more versatile. The cost difference of the component types is small. The fixed head star tracker has more complex on-board software, and involves slightly more data processing to obtain an operational star catalog than the star crossing detector, but the on-board computer appears capable of handling the equations, and the cost is non-recurring. Since this cost is required for an inertial mission or solar max mission which do require star trackers, it represents an extra overall cost if star crossing detectors are used for EOS-A. The cost of using star trackers for all missions is approximately $169,000 less than developing both star trackers and star crossing detectors to minimize recurring costs. If SMM and Inertial Missions are excluded, the cost of using all star crossing detectors is approximately $64,000 less than using all star trackers.

3.6.5 INERTIAL REFERENCE UNIT TRADE STUDY

The Inertial Reference Unit (IRU) supplies rate and position data about three orthogonal axes for spacecraft control. The IRU referenced in the GSFC specification is composed of three orthogonal single axis gyros of the ball bearing type. Since the ball bearing type of gyro is gradually being replaced by gas bearing types, for the space application, the IRU baseline has been assumed to contain gas bearing gyros.

An alternate approach is to use two double degree-of-freedom gyros to obtain a three-axis IRU.

Trade Studies. IRU requirements relating directly to the problem of providing a gyro and caging loop design capable of integrating vehicle rate accurately are summarized in Table 3-44.

Table 3-44. IRU Requirements

	High Gain Requirement (Acquisition)	Low Gain Requirement on orbit "normal"mode
Rate Range	3 deg/sec	.2 deg/sec
Position Jitter over 17 minutes	.015 deg	.001 deg
Short-Term Random Drift ($1.4 * 10^{-4} < f < 1.$ Hz)	.045 deg/hr	.003 deg/hr
Noise $f > .1$ Hz	5.4 deg/hr RMS	.36 deg/hr RMS
Gyro Bandwidth (caging loop)	3 Hz	3 Hz
Pulse Weight (LSB)	0.9 sec	.06 sec

These requirements indicate a very accurate rate sensing capability but offer relief in the area of frequency response, since there are no demands in the vehicle requirements for response to step inputs. It is this relief that permits the use of two degree of freedom "dry gyros" as a rate sensing device (Table 3-45). The two degree of freedom dry gyro is presented in Figure 3-39 showing a cut away view from the side.

Vehicle rate will react with wheel momentum causing precession about the pivot which is detected by a conventional micro-syn pick-off and converted to a rebalance torque in a caging loop. To date, this loop has been analog for the dry gyro and development is required to assure that a digital caging loop is feasible. Should analog caging remain advisable, the EOS digital interface format can still be met by using an analog-to-digital

Table 3-45. Vendor Response to Requirements

Item	Vendor A	Vendor B	Vendor C	Vendor D
Inertial element	Single degree of freedom floated triad	Single degree of freedom floated triad	Single degree of freedom floated triad	Two double degree of freedom dry gyro- "flex gyro"
Suspension	Magnetic and floated	Taut wire and floated	Jewel pivot and floated	Flex pivot
Caging Loop	Pulse width modulated	Pulse width modulated		Analog
Do Word Recovery	Up-down counter	Up-down counter		Pulse on demand re-set integration
Drift over 15 minutes	$<.00^{\circ}$ 1 hr $.003^{\circ}$/hr	$\approx .003^{\circ}$/hr		$.006^{\circ}$/hr
Position jitter over 15 minutes	.0004 deg	<.0006 deg		
Rate noise f >.1 Hz	$.3^{\circ}$/hr RMS			
Weight				
Weight				
Cost (thousands of $)				
-fixed	375	910	(3500)	483
-recurring (10)	350	1600		1460

pulse on demand electronic integration similar to the Block 5 vehicle reference design. Not shown in Figure 3-39 is the second set of pick-off and torquer coils located along the third orthogonal axis (normal to the page), allowing rates about two axes to be detected by a single spun wheel.

Advantages in the design of Figure 3-39 that lead to lower recurring costs are: the wheel is not floated in a thermally controlled viscous fluid making fewer high-quality precision manufacturing processes required; and only two wheels are required to provide three axes of rate information. Note that a fourth rate channel is automatically available for providing a measure of system performance.

To date, space application of this type of rate sensor is not widespread, but the concept is well proven in airborne and ground reference system applications. The light version of these sensors proposed for EOS offers significant recurring cost savings, justifying the additional vendor surveillance responsibility to assure that reliability, noise and drift and computer interface requirements can be met over vehicle life.

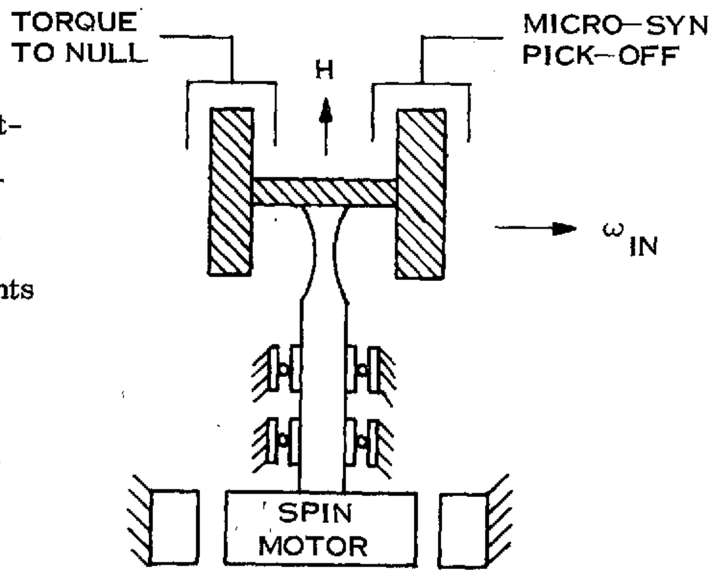

Figure 3-39. Dry Gyro Concept

Conclusions. The double degree of freedom gyros are recommended since they are capable of meeting the requirements and are significantly lower in cost (approximately $510,000 for ten IRU's. They do, however, have specific characterisitcs which must be further evaluated from the ACS standpoint prior to finalization of the selection.

3.6.6 REACQUISITION TRADE STUDIES

The EOS type ACS is optimized to operate about small angular derivations from the nominal altitude. During initial acquisition, the errors are not small and the spacecraft may be unable to stabilize itself with the normal ACS logic. It is, therefore, necessary to develop a technique which enables the spacecraft to operate successfully at large attitude uncertainties, and to reduce these uncertainties to a point where the normal ACS can assume control.

Baseline Approach. The baseline acquisition sequence is described in the GSFC specification and is shown in Table 3-46. The procedure requires a coarse sun sensor, and a digital sun sensor, with a magnetometer as a backup or assist.

Table 3-46. Baseline Acquisition Sequence

Item	Procedure	Sensing Components
1	Reduce S/C rates and orient Solar Array to Sun	Coarse Sun Sensor Inertial Reference Unit
2	Conduct Star Search about sun line	Star tracker or Magnetometer and sun sensor
3	Switch Pitch and Roll Control to Fixed Star Tracker	Star Tracker
4	Switch Yaw Control to Digital Sun Sensor	Digital Sun Sensor
5	Update IRU and Switch Control to IRU	IRU

Alternate Approach. The alternate approach is to use the Solar Aspect Sensor, the Star Sensor, and the on-board computer with appropriate software.

Trade Studies. The baseline acquisition approach is oriented primarily towards a ground controlled step-by-step acquisition, gradually acquiring a more accurate attitude reference. When the reference has been obtained, the IRU is updated.

The acquisition procedure can be considerably simplified by using the computer in conjunction with the IRU, the solar aspect sensor and the star tracker. The procedure is similar to the normal operation mode except that the sun is used as an indirect attitude reference and the maneuvers are about the sun line and are large. The procedure consists of orienting the spacecraft to the sun using the solar aspect sensor, and then by ground command (or autonomously) correct the quaternions. The error in the corrected quaternions will be about the sun line. The spacecraft will then rotate about the sun line until a bright star is identified, at which point the update procedure will start, using the stored star data. After the attitude is established, the spacecraft can initiate normal operations. The procedure eliminates the need for a fine sun sensor, a coarse sun sensor, and a magnetometer, as well as the affiliated software.

Conclusions. The fine sun sensor, coarse sun sensor, and magnetometer can be eliminated from the baseline configuration. There are several acquisition sequences (such as the one described above) which can be implemented using the computer, the star tracker and the Solar Aspect Sensor.

3.6.7 FINE REACTION CONTROL SUBSYSTEM COST TRADE

Torques which are constant in inertial space (termed secular torques) cause the spacecraft momentum to increase indefinitely and the momentum must be periodically (or continuously) "unloaded" from the spacecraft.

Under normal ACS operation, magnetic unloading systems will unload the momentum without disturbing the spacecraft. In the event that the magnetic unloading system malfunctions, however, momentum can be unloaded using existing components, with spacecraft disturbance, or unloaded without the disturbance by adding components.

Baseline Approach. The fine reaction control subsystem provides the spacecraft with momentum wheel unloading capacity which minimizes the disturbance to the spacecraft.

Alternate Approach. The alternate approach is to use the coarse reaction control subsystem which is normally used for boost/orbit correction maneuvers. The spacecraft will be disturbed by this approach, but the impact can be minimized by appropriate computer software.

Trade Studies. The use of a fine reaction control subsystem to unload without disturbing the spacecraft has been completely established on OAO.

The ability to unload momentum wheels with a torque level much higher than the momentum wheel torque has been established on Nimbus and ERTS. The approach is to fire the thruster for a fixed time increment and then inhibit the thruster for a specified period of time (approximately 300 seconds) until the momentum wheel has stabilized. The delay prevents instability caused by the wheel time constant.

For EOS, the unloading procedure can be greatly improved by using the OBC to minimize the disturbance to the spacecraft, The OBC would determine the momentum at which unloading would occur, and command the wheel to reduce speed. The speed reduction will continue for several seconds until half the momentum to be unloaded is "out" of the momentum wheel, at which point the thruster will be fired for a fixed time increment. The wheel speed will continue to reduce with the RCS inhibited until the nominal amount of momentum has been removed, at which point the unloading will stop. The ACS will correct for attitude and rate errors created by the maneuver, and for the mismatch between the actual momentum removed and the nominal value. A computer simulation of the unloading procedure with preliminary spacecraft parameters, showed a peak pitch error of 14 arc seconds, and a peak rate of 1.2×10^{-3} deg/sec. The errors are reduced to .18 arc seconds and 10^{-6} deg/sec in approximately 28 seconds. The errors are larger on yaw, but the settling time is nearly the same.

For the EOS-A mission, the alternate approach is compatible with the payload requirements. The disturbance imparted to the spacecraft is small and recovery is rapid. The maneuver will not be performed during payload operation, and therefore will not impact the payload performance. The ACS requirement imposed by this restriction is that the momentum acquired during payload operation does not exceed the momentum capability of the wheels. The rate of accumulation of momentum is approximately 1.28 lb/sec/orbit. For the longest payload operating period of 35 minutes, and with a ten minute margin, the total momentum accumulation (per wheel) is 0.58 lb-sec, approximately 36 percent of the wheel capability. An unloading prior to payload operation will prevent the need for an unloading during payload operation. This unloading may be timed by ground command, or performed automatically by keeping the momentum level of the spacecraft low at all times.

For the SEOS spacecraft, where magnetic unloading is not practical, the tradeoff applies to the Normal mode. The feasibility of the approach is dependent upon the payload requirements, operating times, etc.; but preliminary studies indicate the alternate approach can be implemented without payload performance impact.

For the Solar Max Mission, the trade exists except the coarse RCS will be selected based upon acquisition, since there is no orbit adjust/boost capability planned. Again, the feasibility will depend upon the payload requirements and operating times.

Conclusion. The alternate approach is recommended for EOS-A and the other low altitude earth observatory missions and for SMM. The coarse reaction control system can effectively backup the magnetic unloading system without affecting payload performance. The approach is also recommended for SEOS. The recurring cost saving for EOS is $90,000.

3.7 COMMUNICATION AND DATA HANDLING DESIGN/COST TRADEOFFS

The performance/cost trades in the C&DH area were aimed at optimizing the performance of the baseline configuration. Although the baseline configuration meets the C&DH requirements, improvements in cost/performance can be obtained in the areas of downlink modulation techniques, party line operation, AOP enhancement and several other areas. The impact of the recommended approach for redundancy and the impact of TDRSS are also assessed. Characteristics of both systems are given in Table 3-47.

3.7.1 ALTERNATE MODULATION TECHNIQUES

Uplink. Four modulation schemes which permit simultaneous command and GRARR were considered:

1. FSK/AM/PM. STADAN baseband with PM carrier modulation (to be used on IUE)
2. PCM/PSK/FM/PM. MSFN standard, 70 kHz subcarrier (used on ERTS); no subbit encoding
3. FSK/AM/FM/PM. Hybrid STADAN/MSFN concept; baseband FM's 70 kHz subcarrier
4. PSK/PM. 70 kHz subcarrier PSK'd with PCM data.

The first scheme has the disadvantage of having the FSK frequencies in the 7 to 12 kHz band which, along with the 2 kbps bit rate, makes the command spectrum too close to the 4800 kHz GRARR tone. Changing the FSK frequencies would be incompatible with existing STDN hardware and require a new design of the S/C demodulator. These frequencies will also cause the first and third schemes to experience intersymbol interference, requiring a ground station change to further separate the signal frequencies.

The second scheme can apparently be generated by the Spacecraft Command Equipment (SCE) which will be available to all ground stations. It is not, however, compatible with the TDRSS command standard and a second S/C demodulator would be required. The fourth scheme is preferred in that it is compatible with both STDN and TDRSS. A suppressed subcarrier demodulator (Costas loop) would be needed in the S/C. The 70 kHz subcarrier is used to separate the command data from the GRARR signals.

Table 3-47. C&DH Characteristics

	Baseline	Optimized Baseline
Command Bit Rate (uplink)	2000 bps	2000 bps
Command Modulation	PCM/PSK - Σ/FM/PM (70 kHz SC)	PSK/PM (70 kHz SC)
Narrowband Data Rate	32, 16, 8, 4, 2, 1 kbps	16, 8, 4, 2, 1 kbps
Narrowband Modulation	Split-phase PCM/PM on subcarrier	Split-phase PCM/PM on subcarrier
Medium Band Data Rate	500 kbps, maximum	500 kbps, maximum
Medium Band Data Modulation	Split-phase PCM/PM on subcarrier	Split-phase PCM/PM on carrier
Transmitter Power	2 watts/0.2 watts	1 watt
T/M Data Coding	Manchester	Manchester
Command Party Line		
Number	One	One
Levels	Three	Two
Data Type	Triangular	Split-phase - Manchester
Word Length	91 bits (pulse), 28 bits (serial)	30 bits
Frequency	16 kbps	8 K words/sec
Information Rate (max)	1 kbps (OBC), 800 bps (ground)	800 bps (ground, 95 kbps (OBC Cmd & TLM)
Telemetry Party Line		
Number	Two	One
Levels	Three	Two
Data Type	Triangular	Split-phase - Manchester
Word Length	16-bit address, 8-bit data	8 bits
Frequency	128 bps (address), 64 kbps (data)	64 kbps
Information Rate	8K words/sec	8K words/sec
Command Remote Decoder		
Number	32, max.	32, max.
Outputs (each remote)	64 pulse, 4 serial	64 pulse, 4 serial
Telemetry Remote Mux		
Number	32	32
Inputs (each remote)	64 (analog, bi-level, 16 serial)	64 (analog, bi-level, 16 serial)
Clock		
Oscillator Frequency	6.4 MHz	3.2 MHz
Oscillator Stability	$\pm 1 \times 10^6$ per day	$\pm 1 \times 10^8$ per year
Frequency Outputs	1.6 MHz, 128 kHz, 8 kHz, major frame, minor frame	All C&DH, 1.6 MHz
Time Code	24 bits	32 bit
On-Board Computer		
Speed		
Add	5 μ sec	5 μ sec
Multiply	38 μ sec	6-10 μ sec
Divide	75 μ sec	75 μ sec
Word Length	18 bits	18 bits (goal, 24 bits)
Memory		
Module Size	8k words	8k words
Total Capacity	64k words	40k words
Type	Core	Core
Access Time	500 nsec	500 nsec
Cycle Time	1.2 μ sec	1.2 μ sec
I/O		
DMA Time	10 μ sec	2 μ sec
DMA Channels	16	10
Execute Time	10 μ sec	10 μ sec
Interrupt Levels	16	16

No cost trade exists in the S/C, except for the extra demodulator required by the second scheme. Ground station delta costs for schemes one and three were not evaluated.

Downlink. No significant cost trades exist in selection of the downlink spectrum except to keep the modulation within the bandwidth of the ERTS transponder (1.5 MHz) while providing simultaneous narrowband (telemetry) and mediumband (NBTR playback, OBC memory dump, GRARR, or 500 kbps instrument) data transmission. Also, it is desirable to keep all carrier modulation balanced (no DC terms) in order to maintain tracking capability. The preferred modulation scheme is to directly phase modulate the carrier with the mediumband data (filtered at 1.5 BR) and place the narrowband data on a subcarrier at 1024 kHz (an available STDN ground station demodulator frequency.

Summary. Both uplink demodulation and downlink modulation schemes can be accomplished using a premodulation processor similar to that used on ERTS. Non-recurring costs are 150K, recurring cost is 90K.

3.7.2 COMMAND AND TELEMETRY DATA BUS TECHNIQUES

The baseline data bus concept was traded off against dedicated wiring to each remote from the CCD or an external junction box. The CCD size is greatly affected by dedicated wiring in that separate transformer drivers are required for each remote, limiting flexibility over a number of different missions. An external junction box would simplify the CCD interface and enhance reliability of each remote, but would greatly increase the power necessary to drive the remotes since all line impedances would have to be matched. In addition, dedicated lines would add ten to fifteen pounds of harness to the spacecraft weight. Neither technique is less expensive to implement than the baseline party line system.

A more significant cost trade involves the use of two data busses instead of three busses for the command and telemetry systems. This is accomplished by using the same data bus for both commands and telemetry addresses. The return bus for telemetry data remains unchanged. The savings is realized in combining the remote command decoder and mux sentry (address decode) logic. This, of course, combines the command and telemetry functions into a single remote module.

The decoder command rate is 125 commands per second, maximum (50 uplink, 75 OBC); the telemetry address rate is 8000 commands per second. Since the command rate is much less than the telemetry address rate, it is feasible to merge these two types of data on a common bus by assigning time slots to each of different types of data. (A command slot would occur every 20 msec to handle uplink commands. The OBC commands would be handled like OBC telemetry addresses.) Coding in the command format would determine how the remote would handle the data. The frequency of the common bus would have to be increased to accommodate the larger word length necessary for serial commands.

A comparison of the common bus and dual bus techniques is given in Table 3-48. Data are given on the basis of a single decoder/mux for the common bus and a pair of remotes (one decoder; one mux) for the dual bus. In addition, 250 mw would be saved in eliminating a line driver for the common bus and an interface between the CCD and the OBC. Size, weight, and cost of this would be made up by the necessary interface circuitry between the CCD and the TFG to integrate commands and telemetry addresses. The data indicate the common bus approach to be more cost effective with savings for a typical system (consist of 10 remotes) of 2.25 watts, 10 pound, and $103 K.

Table 3-48. Common Bus and Dual Bus Techniques

	Size*	Weight*	Power*	Cost*
Dual Bus	50 in^3	2.5 lb	1.4 W	$ 188 K (NR) $ 13 K (R)
Common Bus	40 in^3	1.5 lb	1.2 W	$ 115 K (NR) $ 10 K (R)

* Per Decoder/Mux Remote

The baseline C&DH system powered its remotes from an AC source in the C&DH module in order to maintain grounding isolation between the C&DH module and the S/S being served by the remote. This isolation can be maintained by using a DC/DC converter within each remote powered by the +28 vdc regulated bus available at the subsystem. The secondary of this converter would be referenced to the C&DH signal ground via the T2S cable serving as the data bus.

Table 3-49. Characteristics of Standard NBTR's

Recorder Capacity	Size	Weight	Rec. Power	PB Power	NR Cost	R Cost
10^8 bits	216 in^3	10.3 lb	5-9 W	8-10 W	100 K	100 K
10^9 bits	980 in^3	28 lb	20-40 W	40 W	250 K	100 K

3.7.4 AOP ENHANCEMENT

An assessment of the minimum and maximum usage of the AOP to perform the various spacecraft functions indicated that the AOP is a reasonable candidate for the OBC. Six other computers were also considered. Table 3-50 shows a summary of the impact of each functional group on processing time and memory required. Size, weight, and power deltas were computed assuming core memory. Use of plated wire memory was not considered due to its high cost. Use of state of the art CMOS LSI semiconductor logic could reduce power by 80% and weight and volume by 50%. A minimum instantaneous load of 39% and a maximum load of 81% is estimated. These are short term peaks in the processing load on the CPU. Average loads range from 31 to 73% of CPU capacity.

Table 3-50. AOP Loading Summary

Function	Δ CPU (Usage %)		Δ Memory (k words)		Δ Power (watts)		Δ Weight (lbs)		Δ Volume (in^3)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Baseline AOP (1 CPU-I/O; 1 8k Memory; 1 Pwr Conv; 1 Pwr Switch	3.0	5.0	8.0	8.0	20.3	20.3	20.0	20.0	403	403
Total Telemetry	1.6	16.7	2.0	7.4	2.0	8.0	3.0	11.1	60.5	235.8
Total Command	5.0	5.0	2.8	2.8	2.9	2.9	4.2	4.2	86.6	86.6
Total Power	0.1	0.3	0.4	0.8	0.4	0.8	0.5	1.2	11.7	23.2
Total Thermal	0.01	0.02	0.3	0.3	0.3	0.3	0.5	0.5	9.5	9.8
Total Antenna Pointing	1.2	12.0	6.5	6.5	6.7	6.7	9.7	9.7	206.1	206.1
Total Performance Monitoring	2.8	5.2	3.4	4.6	3.5	4.7	5.0	6.8	110.4	145.6
Total ACS	24.9 Inst 17.4 Avg	36.4 Inst 29.0 Avg	3.4	6.8	3.5	7.0	5.1	10.1	107.9	216.2
Total Payload	0.01	0.01	1.6	1.6	1.6	1.6	2.4	2.5	50.0	50.0
Total Propulsion	0.4	0.4	0.5	0.5	0.5	0.6	0.8	0.8	16.0	16.0
Total - All Systems	36.0 Inst 28.5 Avg	76.0 Inst 68.6 Avg	20.9	31.3	21.4	32.5	31.2	46.8	658.7	989.3
Total - All Systems + A01	39.0 Inst 31.5 Avg	81.0 Inst 73.6 Avg	28.9	39.3	41.7	52.8	51.2	66.8	1061.7	1392.3

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The following options were considered to enhance the AOP CPU and an assessment made on CPU performance and implementation complexity.

1. The AOP DMA (Direct Memory Access) technique can be modified to achieve a word insertion or extraction in one memory cycle instead of five. This modification can be performed with two external "hardware" registers for each DMA user. The cost of these 18 or 24 bit registers, even if there should be twenty registers for ten users, is small (25 K non-recurring, 20 K recurring) when compared with the entire AOP cost. At most a few standard semiconductor chips will be involved. The resulting five to one increase in DMA data transfer rate reduces the percentage of CPU time consumed in exchange of TLM data and addresses with the Telemetry Format Generator (TFG) by about 4%. Table 3-50 assumes this option included.

2. Either an elapsed time counter or command chaining/linking capability can be added to the AOP CPU. An elapsed time (interval) counter (ETC) is preferred since this entails minimal impact on the existing AOP design and also does not involve additional programming complexity. The ETC would be particularly useful in delayed command processing and in antenna pointing. Total CPU time used for command would be reduced from 5% to 0.5%. Implementation cost should be quite small (15 K non-recurring, 5 K recurring). Although not included in the estimates of Table 3-50 it is recommended to be incorporated.

3. "Vector subtraction" or "vector comparison" in one instruction is another desirable function. This would permit a repetitive set of subtracts or comparisons to be performed within one instruction instead of requiring repeated (iterated) instruction loops. Thus, the m dimensioned vector (a_1, $a_2 \ldots a_m$) could be subtracted from the vector (A_1, $A_2 \ldots A_m$) in one instruction with any negative results being appropriately noted. This feature could reduce the demands of such TLM functions as limit checking, status checking, and alarm checking by 3 to 1 and would be a desirable feature. Incorporation internal to the CPU could entail significant logic design changes; however, it is felt this feature could be designed as an external I/O function, accessible to the CPU and not involve a substantial CPU design change.

4. Incorporating a high speed multiply capability within the AOP would reduce multiply time from 38 μs to 6 to 10 μs. This would entail significant logic changes in the CPU but the high speed multiplication function could be incorporated as an external I/O function with a minimal impact on the existing AOP-CPU design. The logic required would be on the order of a few hundred gates.

5. Another feature to enhance the AOP-CPU is a scaler ("dot") product generator. This would be particuarly useful in the ACS functions. It could also be implemented as an external I/O function. If a high speed multiply capability is implemented, inclusion of the scalar product function becomes less vital.

The current 18 bit version of the AOP is capable of supporting all of the EOS A functions without any of the above modifications and with 40K (five 8K modules) of memory. The CPU loading can be improved by any of the above techniques, however firm recommendations for their inclusion must be based on more detailed preliminary design. ACS performance analysis indicates that the 24 bit version of the AOP would be a beneficial, but not a necessary, improvement.

3.7.5 IMPACT OF REDUNDANCY

Redundancy was considered on the basis of minimizing weight, power and cost while maintaining a capability of shuttle servicing in case of failure. Based upon this criteria, the following redundancy is recommended:

Transponder, command demodulator, central command, decoder and clock. A redundant link is desirable. It assures the capability of putting the spacecraft into a safe mode and into the proper orbit for shuttle servicing. The transmitter section of the transponder must be redundant to maintain tracking capability. Redundancy will be standby, with the OBC selecting redundant channel if uplink is not sensed within a certain period of time ($\sim$ 3 orbits).

Data busses and remotes. The partyline technique and desire for command redundancy dictate use of redundancy.

The cost of this redundancy is 5 watts, 27 pounds and 180 K recurring cost. This compares with the cost of a fully redundant C&DH module of 8 watts, 99 pounds and 615 K in hardware.

3.7.6 IMPACT OF TDRSS

The TDRSS assessment assumes the following:

1. Forward Link

   a. Command and ranging via TDRSS (multiple access or single access, when available) through EOS omni-antenna. Command rates would be limited to 100-200 bps, but contact time would be longer.

b. Monopulse carrier from TDRSS at Ku band through high gain EOS dish (8' to 12')

c. Maintain STDN command (2000 bps) and GRARR link

2. Return Link

a. Narrowband telemetry and ranging from EOS at S-Band through high gain EOS dish (MA or SA)

b. Narrowband telemetry and ranging via EOS omni antenna at reduced rate (~ 100 bps)

c. Maintain narrowband, medium band, and ranging link to STDN

The above requirements necessitate the development of a TDRSS transponder. The transponder will lock to the carrier, demodulate the PN code and command data, handle the ranging tones, and transmit spread spectrum narrowband telemetry data PSK on the carrier. This transponder must be added to the existing C&DH module (no TDRSS). It is estimated to cost 350 K (recurring) for a non-redundant unit, weight 25 pounds and require 25 watts of power.

Section 4

GROUND SYSTEM COST TRADEOFFS

This section describes the design/cost tradeoffs for the various ground system segments and provides cost elements for the ground system segments that are traded at the system level (in Section 2).

The section is organized as follows:

- Section 4.1 discusses the design/cost tradeoffs associated with modifications to the Networks and NASCOM.
- Section 4.2 discusses the design concept and design/cost tradeoffs for the Operations Control Center (OCC) and Data Services Element (DSE).
- Section 4.3 discusses the design concept and design/cost tradeoff for the Image Processing Element (IPE), and
- Section 4.4 discusses the design concept and design/cost tradeoff for the Low Cost Readout Station (LCRS).

4.1 NETWORK/NASCOM DESIGN/COST TRADEOFFS

4.1.1 X-BAND RECEPTION AT THE PRIME NETWORK STATIONS

A. Purpose and Summary

The purpose of the study was to provide a tradeoff comparison of alternatives for adding the capability at the prime EOS Network Stations (Fairbanks, Goldstone and Network Training and Test Facility) for receiving the HRPI and TM wideband data at X-band.

The two alternatives considered were as follows:

- Addition of a new 30-foot antenna system designed for X-band for acquisition, tracking and reception at each of the three prime network stations or

- Modification of the existing 30-foot USB antenna systems at Goldstone and Network Training and Test Facility and the 40-foot telemetry antenna system at Fairbanks to include a dual S-band/X-band feed system.

On the assumptions that: (a) the existing antenna systems identified above are available for modification; (b) down-time for the antenna systems for the modifications can be scheduled into the network activities; and (c) existing reflector surface tolerance and S-band tracking accuracies will be verified not to cause more than a 2.0 dB degradation on the antenna receiving gain at X-band, then modification of the existing antenna systems to handle X-band reception at the prime network stations is the preferred approach. This approach provides acceptable performance along with both the lowest initial and lowest operations/maintenance costs.

B. Requirements and Analysis

Performance Characteristics of a New 30-foot X-Band Antenna System

Table 4-1 provides preliminary link margin calculation for the EOS wideband data @ 8 GHz. The overall link margin is 7.9 dB.

Performance Characteristics of Existing Antenna Systems @ S-Band

Table 4-2 provides the performance characteristics for the three prime EOS network stations obtained from document STDN No. 101.1 entitled "Spaceflight Tracking and Data Network User's Guide", dated April 1972 and from verbal discussion with NASA network personnel.

TABLE 4-1. WIDE BAND DATA LINK MARGIN CALCULATIONS

Frequency: 8 GHz		
Power Generated	dBm	36.0
Transmitter Gain	dB	30.0
Modulation Loss	dB	0
Trans. Circuit Loss	dB	-2.0
Eff. Radiated Power	dBm	64.0
Trans. Pointing Loss	dB	-1.0
Space Loss	dB	-180.7
Propagation Loss	dB	-5.0
Rec. Signal Relative to Isotope (RSS)	dBm	-122.7
Receiver Pointing Loss	dB	-0.5
Polarization Loss	dB	-0.2
Receiver Gain	dB	55.0
Receiver Signal	dBm	-68.4
Rec. Noise Density	dBm/Hz	-173.5
Noise Bandwidth (240 MHz)	dBHz	83.8
Link Noise	dBm	-89.7
Link SNR (in 240 MHz)	dB	21.3
Required SNS (in 240 MHz)	dB	13.4
Link Margin	dB	7.9

TABLE 4-2. PERFORMANCE CHARACTERISTICS OF EXISTING ANTENNA SYSTEMS CONSIDERED FOR EOS UTILIZATION

Network Station / Performance Characteristics	• Network Training and Test Facility • Goldstone	• Fairbanks
Antenna Size	30' USB	40' Tracking
Gain: T_X @ S-band	42.5 dB	----
R_X @ S-band	43.5 dB	45.0 dB
Beamwidth @ S-band	1.0°	0.8°
Reflective Surface Tolerance	0.030" RMS (new)	0.060" RMS (new)
Tracking Accuracy @ S-band:		
Raw Data	0.04 to 0.08°	
Smooth Data	0.01 to 0.02°	

The primary impacts on the modified antenna system are as follows:

- Improved antenna receiver gain @ X-band,
- Degradation due to reflector surface tolerance, and
- Degradation due to tracking @ S-band.

The antenna receiver gain is increased by 12 dB by increasing the frequency from 2 GHz (S-band) to 8 GHz (X-band).

The degradation in dB due to reflector surface tolerance is shown on Figure 4-1. The effects of a one-third and one-half change from the initial design tolerances for the 30-foot USB antenna system and 40-foot telemetry antenna system are tabulated on this figure.

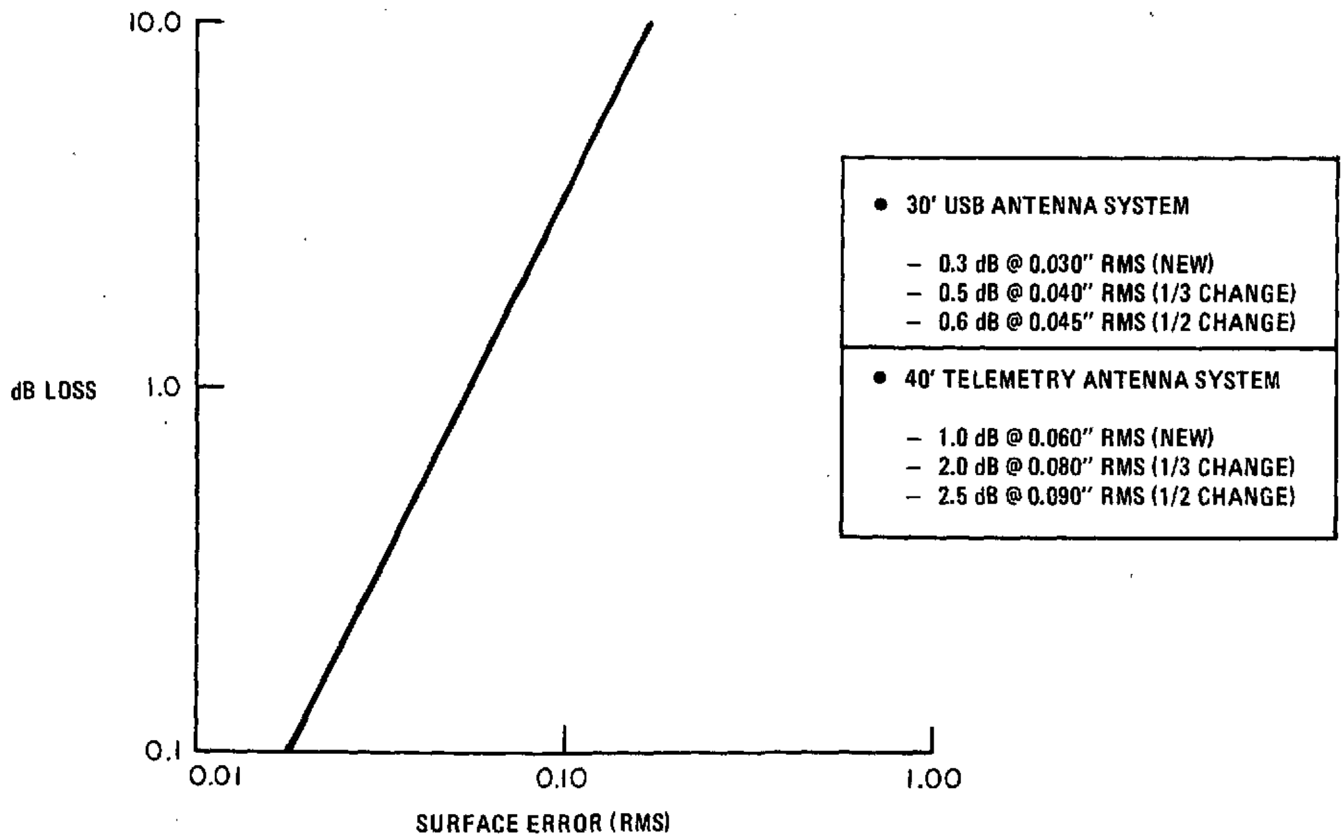
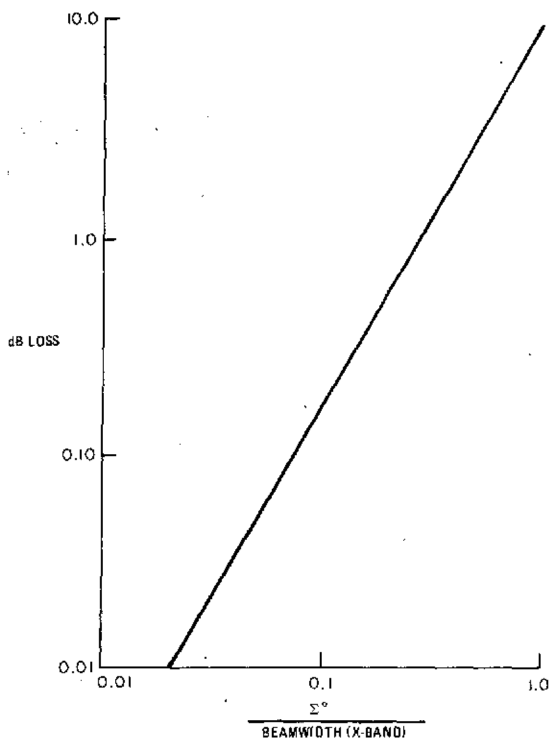


Figure 4-1. Loss Due to RMS Surface Error at 8 GHz

The degradation in dB due to tracking at S-band is shown on Figure 4-2. The effects of the largest accuracy values for smooth data (.02°), raw data (.08°) and an error of 0.1° for the 30-foot USB antenna system are tabulated on this figure.

Since no values were available at the time of preparation of the results of this study for the 40- foot telemetry antenna system, it was assumed that the S-band tracking accuracy was directly proportional to the S-band beamwidth and the degradation of the X-band signal therefore would be the same as the 30-foot USB antenna system.

Table 4-3 provides a comparison of the significant parameters for the new antenna system and the modified antenna systems. The degradation associated with the modified antenna due to a 50% change in reflector surface tolerance from the original specifications and degradation due to tracking @ S-band with a 0.10° error for the 30-foot USB Antenna System or a 0.08° error for the 40' Telemetry Antenna result in a 1.9 dB loss. Since this comparison was done with a new antenna design, the resulting link margin of the modified antennas would be 6.4 dB for the 30-foot USB Antenna System and 6.0 dB for the 40-foot Telemetry Antenna which are acceptable design points.



• 30' USB ANTENNA SYSTEM

Σ° (S-BAND)	BEAMWIDTH° (X-BAND)	Σ°/BEAMWIDTH°	dB CHANGE
0.02°	0.25°	0.08	-0.07 dB
0.08°	0.25°	0.32	-1.2 dB
0.10°	0.25°	0.40	-1.9 dB
0.12°	0.25°	0.48	-2.3 dB

• 40' TELEMETRY ANTENNA SYSTEM

Σ° (S-BAND)	BEAMWIDTH° (X-BAND)	Σ°/BEAMWIDTH°	dB CHANGE
0.16°	0.2°	0.08	-0.07 dB
0.64°	0.2°	0.32	-1.2 dB
0.80°	0.2°	0.40	-1.9 dB

Figure 4-2. Gain Reduction Due to Tracking Error

TABLE 4-3. COMPARISON OF NEW ANTENNA SYSTEM VS. MODIFIED ANTENNA SYSTEM

Configuration / Parameters	New 30' X-band Antenna System	Modified 30' USB Antenna System		Modified 40' Telemetry Antenna System	
	Value	Value	Delta	Value	Delta
Antenna Gain	+55.0 dB	+55.5 dB	+0.5 dB	+57.0 dB	+2.0 dB
Degradation of 50% Change on Surface Tolerance	—	-0.6 dB @0.045" RMS		-2.5 dB @0.090" RMS	
Degradation Due to Tracking at S-band	—	-1.9 dB @0.10°		-1.9 dB @ 0.08°	
Allocation of Receiver Pointing Loss	-0.5 dB				
			-2.0 dB		-3.9 dB
Accumulative Delta			-1.5dB		-1.9 dB

C. Definition of Design Alternatives

New 30-Foot X-Band Antenna System

This approach utilizes a Cassegrain antenna similar to the existing antenna except that the tolerances are specified for X-band. In this approach tracking will be done at X-band to realize the benefit of the improved tolerance.

Modification of Existing S-band Antenna Systems

Figure 4-3 is a schematic representation of the modified S-X feed system. This involves the use of a dichroic subdish-feed combination with S-band at the prime focus. Tracking is assumed at S-band.

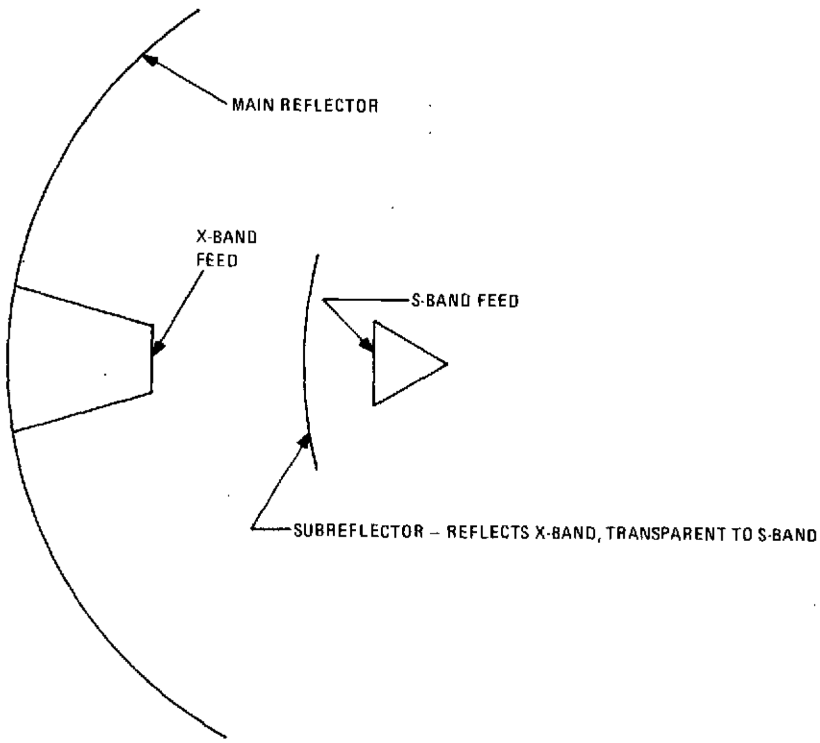


Figure 4-3. Dual S-X Band Feed System

D. Design/Cost Tradeoff

Tradeoff Criteria

The criteria utilized in the selection of the alternatives were:

- Performance
- Initial costs
- Existing antenna system availabilities and permitted down-time, and
- Operational considerations and costs.

Performance

The performance of both alternatives has been discussed. The resulting degradation due to the modification of the existing antenna systems can be absorbed into the present link margin; therefore performance is not a major tradeoff factor.

Initial Costs

The initial costs for the two alternatives are shown on Tables 4-4 and 4-5 for the new and modified antenna approaches respectively. The modified antenna approach has a significantly lower initial cost ($33K vs $1,400K).

Existing Antenna System Availability and Permitted Down-Time

This tradeoff factor only applies to the modified antenna approach. It is assumed that the antenna systems identified will be available for modification to combined S-band and X-band and that the down-time due to the modification can be scheduled into the network activities (critical phases of the modification could be done on a three-shift basis to minimize down-time of the prime antenna system).

TABLE 4-4. INITIAL COSTS FOR NEW 30 FOOT X-BAND ANTENNA SYSTEM

Cost Item		Cost
• New antenna system including reflector, feed support assembly, feedhorn ring, adapter and counterweights, El - Az mount, servo control drivers and controls and pedestal (tower) for ground clearance, monopulse prime focus feed and combining network.		\$300K
• Additional tracking electronics required for X-band.		\$ 40K
• Installation at prime network station including foundations, assembly, shipping, checkout assuming workable time of the year and adequate soil conditions.		\$ 85K
	Subtotal	\$425K/system
		X 3 systems
		\$1,275K
	~10% Contingency	125K
	Total	\$1,400K

TABLE 4-5. INITIAL COSTS FOR MODIFIED S-BAND ANTENNA SYSTEMS

Cost Item		Cost
• S-band and X-band feed system for existing antennas, including feeds and combining network to RF output.		\$ 80K
• Electronic and servo modifications		Assumed negligible
• Installation and Test		\$ 20K
	Subtotal	\$100K/system
		X 3 systems
		\$300K
	~10% Contingency	30K
	Total	\$330K

C-3

Operational Considerations and Costs

A major advantage is inherent in the modified antenna approach since it reduces operational complexity by utilizing only one antenna system during contact with the EOS spacecraft. The one antenna is used for command, telemetry, tracking and data collection platform data at S-band and HRPI and TM data at X-band. Another advantage in this approach is the reduced operational cost associated with maintenance and spares since only one antenna is involved.

E. Recommended Approach

Initial Design Selection

Modification of existing antenna systems at the prime network stations is the preferred approach on the basis of initial costs, operational considerations and costs, and acceptable system performance.

In making this selection, it was assumed that the antenna systems identified will be available for modifications and that down-time for the modifications can be scheduled into the network activities. It was also assumed that the factors effecting degradation of modified antennas (reflector surface tolerances and S-band tracking accuracy) will be verified by NASA and found to be acceptable.

Further Considerations

In the event the new 30-foot S-band antenna system would be required it should be traded off against a new 30-foot combined S-band and X-band antenna system on the bases of cost versus reduced operational complexity plus the mission availability of an S-band antenna system at the prime network stations.

Other Factors

Area coverage over the United States by the three prime stations has been shown to be marginal near 500 nmi satellite altitude with increasing gaps over the mid-southern states at lower altitudes (see Section 3.2 of Report No. 1 for details). In the event that an additional prime EOS network station is required to supplement and/or replace the NTTF station, the prime candidate is Merrit Island. Merrit Island has a 30-foot USB antenna system identical to the ones considered in this study and the use of this station would not affect the foregoing cost trade results.

4.1.2 WIDEBAND TRANSMISSION BETWEEN NETWORK TRAINING AND TEST FACILITY AND THE GROUND DATA HANDLING SYSTEM FACILITY

A. Purpose and Summary

The purpose of the study was two-fold:

- To investigate and tradeoff various microwave link and co-axial cable configurations for real-time transmission of the wideband data received at the NTTF to the Ground Data Handling System Facility at GSFC Bldg. 23, and
- To evaluate the operational and cost impacts of the real-time transmission approach as opposed to the standard network procedure of recording the data on high density digital tapes at the NTTF and forwarding these tapes to the Ground Data Handling System Facility.

Both microwave link and co-axial cable link configurations are feasible for real-time transmission of the wideband data from the NTTF to the Ground Data Handling System Facility (GDHSF). The preferred link configuration is a co-axial cable which transmits the data at the IF spectrum ($\sim$800 MHz). The cost advantage inherent in the reduction of the number of high density digital tape recorders (HDDTR's) does not outweight the major disadvantages of impact on available image processing time and added complication to the NTTF/GDHSF interface. The preferred configuration is a NTTF similar to the other network configurations for real-time recording of the HRPI and TM data.

B. Requirements

The primary requirements for the real-time transmission link are:

- Minimum performance degradation of the wideband data caused by the transmission link (i.e., BER of $\leq 1 \times 10^{-6}$),
- High reliability of the transmission link since downtime of the link during real-time transmission of the data from the EOS Spacecraft to NTTF will result in loss of this data.

C. Real Time Transmission Link Configurations

General

Relay of the wideband data may be accomplished at any of the following three spectrum areas:

- R/F (approximately 8.2 GHz) - applicable to microwave link transmission techniques.
- I/F (approximately 800 MHz) - applicable to co-axial cable transmission techniques;
- Baseband (two channels @ 120 Mbs each) - applicable to co-axial cable transmission techniques.

A block diagram of the various real-time transmission link configurations discussed in following paragraphs is shown on Figure 4-4.

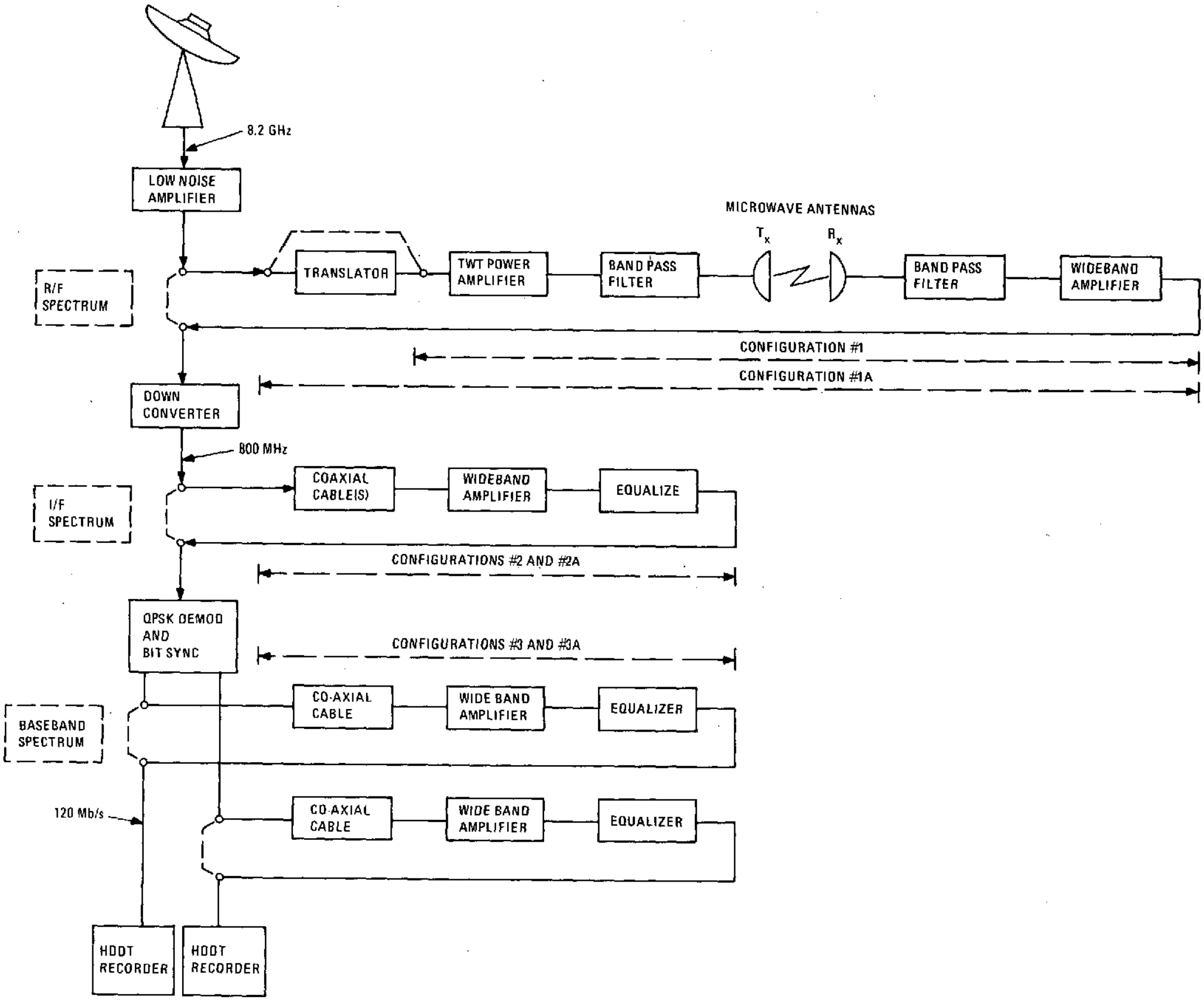


Figure 4-4. Real Time Transmission Link Configuration Block Diagram

Microwave Link Configurations

The microwave link configuration (configuration #1) is based on applying the output signal from the NTTF low noise amplifier, prior to the IF down converter, to a suitable traveling wave tube amplifier and band pass filter which would feed a 4-foot parabolic 8 GHz microwave antenna for radiation to Bldg. 23. At the latter location a similar antenna would receive the signal and after suitable band pass filtering and wideband amplification would provide the signal to the IF down converter. All active electronic equipment would be redundant in this configuration. This approach obviously implies a bandwidth equal to or greater than the downlink from the spacecraft. Additionally the same carrier frequency would be employed in co-channel operation.

Two detremental factors are associated with this approach - potential R/F interference between the prime receiving antenna and microwave transmitting antenna as well as potential NASA and FCC objections to radiation of 300 MHz bandwidth at 8 GHz which is far in excess of bandwidths normally used for terrestial links.

An alternative configuration (configuration #1A) to the approach discussed above, which circumvents potential R/F interference, would apply a mixer or translator to shift the carrier frequency to a different assignment prior to amplification and re-radiation.

Co-Axial Cable Link Configuration Alternatives

Normally a major cost element associated with co-axial cable link approaches is the cost for excavation and installation of cable ducts. Since suitable cable ducts already exist between NTTF and Bldg. 23, a co-axial cable link approach is considered a viable alternative to the microwave link.

Two configurations utilizing co-axial cable links are possible; one configuration would provide for transmission at IF spectrum, the other configuration would provide for transmission at baseband.

The first configuration (configuration #2) would employ the output signal from the NTTF IF down converter directly to a one and five eighth inch low loss dielectric cable approximately 3000-foot in length. At Bldg. 23 the output of the cable would feed an amplifier having a wide frequency response characteristic and a gain of approximately 18 dB to accommodate the cable loss. This is followed by an equalizer to accommodate the slope in antennuation characteristics of about 4 dB over the bandwidth. (Note: the wideband amplifier and equalizer requirements are based on the characteristics of an Andrews HJ7-50A cable). The amplifier portion would be redundant in this configuration.

An alternative (configuration #2A) incorporates a redundant cable for insurance against long-term outages in event of a cable failure which would require removal, repair and re-installation.

The second co-axial configuration (configuration #3) would be a slight variation to configuration #2 and is based on transmitting the two 120 Mbs data streams via two parallel cables. Amplification and equalization would again be required but the design problems would be reduced at the lower frequency. The amplifier portion would be redundant in this configuration also.

An alternate to this configuration (configuration #3A) would incorporate a third cable for redundancy for assurance against long-term outages.

Comparison Between Microwave and Co-Axial Cable Configurations

The various microwave and co-axial cable approaches were configured to meet the performance requirements so cost is the major tradeoff factor. Tradeoff data is presented in Table 4-6.

The preferred microwave configuration is 1A. The increase cost of approximately $2K over configuration #1 is considered reasonable to shift the carrier to circumvent potential R/F interference problems between the prime receiving antenna and the microwave transmitting antenna.

TABLE 4-6. TRADEOFF DATA ON MICROWAVE LINK AND CO-AXIAL CABLE CONFIGURATIONS

Tradeoff Parameters \ Configurations	Microwave Link Configurations		Co-Axial Cable Configurations			
	#1	#1A	#2	#2A	#3	#3A
Cost (in K $)						
• Design Requirements/Specifications	2.5	2.5	1.5	1.5	1.2	1.2
• Design	4.0	4.0	1.0	1.0	0.8	0.8
• Hardware	19.9	21.9	16.0	30.1	30.1	44.2
• Installation & Test	6.0	6.0	2.1	2.4	2.4	2.6
TOTAL	32.4	34.4	20.6	35.0	34.5	48.8
Other Considerations						
• Potential R/F interference between prime antenna & microwave transmitting antenna	yes	no	n/a	n/a	n/a	n/a
• Potential NASA and FCC Regulation Restrictions	yes	yes	no	no	no	no
• Potential Long Term Outages with single cable failure	n/a	n/a	yes	no	yes	no

Recommended Configuration

Comparison of the co-axial cable configurations #2 and 2A versus 3 and 3A shows a major cost difference in favor of configurations #2 and 2A; the primary cost delta is attributed to the additional co-axial cable required in configuration #3 and 3A. The preferred co-axial configuration then is configuration #2A which incorporates a redundant cable for insurance against long term outages in event of cable failures at locations not immediately accessable for repairs.

The recommend real-time transmission link is co-axial cable (2A) because it eliminates the potential NASA and FCC objections to radiation of 300 MHz bandwidth at 8 GHz at approximately the same price of the microwave configurations.

D. Cost/Design Tradeoff Factors

Configurations to be Considered

Two HDDTR's are required at NTTF for real-time recording of HRPI and TM data from the spacecraft; two HDDTR's are presently required at the GDHSF for processing of the recorded HRPI and TM data. Since the HDDTR's are major cost items (approximately $150K each) and the utilization of the HDDTR's at the NTTF is low, various configurations which time share these units are possible. Configurations to be considered in the tradeoff are as follows:

- A reference configuration which has two HDDTR's at NTTF and two HDDTR's at the GDHSF, and
- Alternative configurations which remove the two HDDTR's at NTTF, have from two to four HDDTR's at GDHSF and employ a co-axial cable link between NTTF and GDHSF to transmit real time data to GDHSF for on-line recovery.

Tradeoff Criteria

The primary criteria to be used in the tradeoff of the various configurations include:

- Cost deltas
- Impact on available image processing time
- Operational considerations, and
- Other factors

The tradeoff data derived in the following paragraphs is listed on Table 4-7. The cost deltas for the various configurations are based on $150 K for each recorder and $35 K for the co-axial cable link.

Impact on Available Image Processing Time

In the alternative configuration A, which employs only two HDDTR's at GHDSF, the recorders must be shared between the on-line recording function and the off-line processing function. Assuming an average recording on 4 passes per day at NTTF and utilization of these recorders, a minimum of 1 hour/pass for pre-pass setup and test and real-time recording, the available image processing time is reduced from 16 hours to 12 hours or by 25%. To compensate for this, the Image Processing Subsystem would have to improve its thruput rate by 33%; the penality is too great to consider this a viable configuration.

In the alternate configuration B, which employs three HDDTR's at the GHDSF, one HDDTR would be available for off-line processing during utilization of the other two HDDTR's for real-time recording. The available image processing time is reduced since HDDTR rewind time is now in-line. For a rewind rate of 2.4 times record rate (based on RCA Model 120G HDMR), the available image processing time is reduced from 3 to 9% depending on total image processing thruput.

TABLE 4-7. TRADEOFF DATA ON REFERENCE AND ALTERNATIVE CONFIGURATIONS

Configuration / Tradeoff Parameters	Reference Configuration	Alternative Configuration A	Alternative Configuration B	Alternative Configuration C
	• 2 HDDTR's @ NTTF • 2 HDDTR's @ GDHSF	• 2 HDDTR's @ GDHSF	• 3 HDDTR's @ GDHSF	• 4 HDDTR's @ GDHSF
Cost Delta	Cost reference	2 less HDDTR's -300K coaxial cable link + 35K Total Delta -265K	1 less HDDTR -150K coaxial cable link + 35K Total Delta -115K	Coaxial cable line +35K Total Delta +35K
Impact on Available Image Processing Time	None	Reduced by 25%	Reduced by 3 to 9% depending on processing rate	None
Operational Considerations -HDDTR Utilization	2 HDDTR's @ NTTF for on-line recording 2 HDDTR's @ GDHSF for off-line recording	2 HDDTR's @ GDHSF for on-line recording and offline processing	1 of 3 HDDTR's @ GDHSF shared for on-line recording and off-line processing	2 HDDTR's @ GDHSF dedicated for on-line recording, 2 HDDTR's @ GDHSF dedicated for off-line processing
-NTTF to GDHSF interface	Simplest-hand carry HDDT to GDHSF	Complex - scheduling, checkout and responsibility	Complex - scheduling, checkout and responsibility	Complex - scheduling, checkout and responsibility
- backup capability for HDDTR	None	None	Yes - three for two	Yes - four for two
Other Considerations	------	real-time display and on-line evaluation of HRPI and TM data possible	real-time display and on-line evaluation of HRPI and TM data possible	real-time display and on-line evaluation of HRPI and TM data possible
	Preferred Approach			

Operational Considerations

Any configuration which removes the two dedicated HDDTR's from the NTTF in favor of location at the GHDSF complicates the interface between them in scheduling, prepass system checkout and responsibility.

On the other hand location of the HDDTR's at a common location which contains three or more units provides backup capability for either the on-line recording or off-line processing functions.

Other Considerations

On-line evaluation of spacecraft/sensor performance as well as real time display of the HRPI or TM data for the Public Information Office is possible when recording of TM and HRPI data is done at the GDHSF.

E. RECOMMENDED APPROACH

Alternative Configuration A

This configuration has the largest cost advantage (negative cost delta of $265K but is not considered a viable alternative to the reference configuration primarily because of the 25% reduction in available image processing time. To improve this processing time, the corresponding increased cost in the image processing element is in the order of $400K.

Alternative Configuration C

This configuration has the disadvantage of increased cost ($35K) and the added complexity of the additional NTTF to GDHSF interface. The primary advantage of this configuration is the backup capability for the HDDTR's.

Failure of one of the HDDTR's in the reference configuration will result in the loss of either the HRPI or TM data during real-time reception at NTTF or will result in reduction of image processing thruput rate in the CDPF. The backup capability, however, is not considered sufficient to outweigh the disadvantages of increased cost and the added complexity of the additional NTTF to GDHSF interface and is therefore not a viable alternative.

Alternative Configuration B

This configuration has a cost advantage (negative cost delta of $115K). The primary disadvantages of this configuration is the 3 to 9% reduction in available image processing time and the added complexity of the additional NTTF to GDHSF interface.

The disadvantages are judged to outweigh the cost advantage and this configuration is therefore not considered to be viable alternative to the reference configuration.

Recommended Approach

Based on the discussion above on the alternative configurations, the reference configuration is the preferred approach.

Modified Reference Configuration

This configuration adds a co-axial cable link to the reference configuration for a cost delta of approximately $20K. The input to this link would be parallelled from either of the HRPI or TM data at baseband at the on-line recording HDDTR interface; the output would be switched into the Image Processing Subsystem just beyond the processing HDDTR.

This configuration has the capability of providing a real time display for the Public Information Office as well as on-line evaluation of spacecraft/sensor performance. A secondary advantage of this configuration would be backup capability for one of the NTTF HDDTR's. From a purely technical standpoint, this additional capability is not required. The public relations value could make it desirable however.

4.1.3 EOS NASCOM DATA TRANSFER REQUIREMENTS

A. Purpose and Summary

The purpose of this study is as follows:

- Establish the EOS data transfer requirements between the remote network stations and the OCC;
- Identify the projected capabilities of the NASA NASCOM data lines to the remote sites; and
- Compare the EOS data transfer requirements with the NASA NASCOM projected capabilities and recommend changes where applicable.

The results of the study are:

- Present EOS-A requirement of 4 kb/s real-time telemetry rate, on-board telemetry dump rate of 80 kb/s, and the on-board computer dump rate of 128 kb/s can be handled within the projected capabilities of the NASCOM data lines.
- The present interface between the NASCOM Center and the OCC of two 56 kb/s data lines requires the present EOS-A on-board computer dump date to be recorded at the Alaska network station and played back after the pass; improvement of this interface to 200 kb/s would remove the restriction.

- The limitation of 28 kb/s for data transfer on the 56 kb/s data lines restricts the EOS real-time telemetry rates to 16 kb/s; this same limitation limits the on-board telemetry dump rate to 160 kb/s for playback of one orbit of recorded telemetry within 40 minutes plus set-up time.

B. Requirements and Analysis

EOS Data Transfer Requirements

The possible EOS data transfer requirements imposed on the NASCOM network can be categorized as follows:

- Real-time data transfer from OCC to remote sites
  - Real-time commands and on-board computer loads up to 2 kb/s total rate. (50 commands/sec x 40 bits/command)
- Real-time data transfer from remote sites to OCC
  - Real-time telemetry at data rate of 1, 2, 4, 8, 16 or 32 kb/s. (Note: Data collection platform data included in real-time telemetry data.)
  - Tracking data at 2 kb/s data rates (10 points/sec x 200 bits/point)
  - Command status at 1 kb/s maximum.
- Near real-time data transfer from remote site to OCC
  - On-board computer dump (all or selected portions) of the 64K words with 18 bits/word at 128 kb/s rate
- Non real-time data transfer from remote site to OCC
  - On-board telemetry dump at data rate of 20 times real-time telemetry rates

- Wideband data transfer from remote sites to GDHS
  - HRPI and TM data to be recorded at prime network stations and forwarded to EOS Ground Data Handling System Facility at Goddard; presents no data transfer requirements on NASCOM networks.

NASCOM Projected Capabilities in EOS Time Era

Table 4-8 provides a summary of the NASCOM projected capabilities of data lines between Goddard Space Flight Center and the remote sites. The capability will consist of 7.2 kb/s data lines and a 56 kb/s data line with the exception of Alaska and Rosman which will have a 1.34 mb/s data line each. Also included in this table is the present communications capabilities of the Network Training and Test Facility and the Operations Control Center.

An interim change to the data lines, being considered by NASA at the present time, calls for upgrading of the 7.2 kb/s data lines to 9.6 kb/s.

NASCOM Data Transfer Format

Data originating at or being forwarded to the remote site is formatted into 1200-bit message blocks; each block consists of 120 bits for header and error code information and 1080 bits for data and filler. Examples of utilization of the 1080 bits would be 128 8-bit telemetry words or 1024 bits and 56 bits of filler or 5 tracking points at 200 bits/point or 1000 bits of data and 80 bits of filler. The effective data transfer rate will be based on 1000 bits of data for a 1200-bit message block. The effective data transfer rate of the 56 kb/s data line is stated as 28 kb/s with the remaining capacity being dedicated to voice, teletype and command circuits.

TABLE 4-8. TENTATIVE NASCOM PROJECTIONS OF DATA LINES TO STDN SITES

	Voice	Data: 7.2 kb/s[(1)] mes. sw.	7.2 kb/s[(2)] ckt. sw.	Wide-band[(2)] ckt. sw.
o EOS Prime Sites				
Alaska	4	2[(3)]	[(3)]	1 @ 1.34 mb/s
Goldstone	4	2	1	1 @ 56 kb/s
NTTF	1	13	-	8 @ 10 MHz (NTTF to OCC)
OCC	4	-	-	2 @ 56 kb/s
o Other Sites				
Ascension	3	2	-	1 @ 56 kb/s
Bermuda	4	2	1	-
Guam	3	2	-	1 @ 56 kb/s
Hawaii	3	2	-	1 @ 56 kb/s
Madrid	3	1[(4)]	1[(4)]	1 @ 56 kb/s
Merrit Island	4	2	1	1 @ 56 kb/s
Orroral	4	2	-	1 @ 28.5 kb/s
Quitoe	3	2	-	1 @ 56 kb/s
Rosman	5	2[(3)]	[(3)]	1 @ 1.34 mb/s

NOTES: (1) mes. sw. - data which requires automated real-time message switching, such as real-time telemetry and command.

(2) ckt. sw. - data which must be handled on a scheduled circuit switching basis, such as site playback of recorded telemetry data.

(3) Included by Time Division Multiplex in wide band.

(4) Additional circuits available which may be scheduled.

C. Utilization of NASCOM Network for EOS Data Transfer

Real-time Data Transfer from OCC to the Remote Sites

The real-time commands and on-board computer loads can be transferred on the present NASCOM 7.2 kb/s lines (6.0 kb/s capacity vs. a 2 kb/s requirement).

Real-time Data Transfer from Remote Sites to the OCC

The real-time data transfer requirements from a remote site to the OCC for possible EOS rates are shown on Table 4-9 along with possible NASCOM Data Line Configurations.

TABLE 4-9. REAL-TIME DATA TRANSFER FROM REMOTE SITE TO OCC REQUIREMENTS AND POSSIBLE NASCOM DATA LINE CONFIGURATIONS

	Data Transfer Requirements				Possible NASCOM Data Line Configuration			
Mode	Real-Time Telemetry Data Rates	Tracking Data Rates	Command Status Data Rate	Total Data Rate (Maximum)	7.2 kb/s line, 6.0 kb/s capacity	9.6 kb/s line, 8.0 kb/s capacity	56 kb/s line, 28 kb/s capacity	
1	1 kb/s	2 kb/s	1 kb/s max.	4 kb/s	1			
2	2 kb/s			5 kb/s	1			
3	4 kb/s			7 kb/s	2 or	1		Present EOS-A Requirements
4	8 kb/s			11 kb/s	2 or	2		
5	16 kb/s			19 kb/s			1	
6	32 kb/s			35 kb/s			1 [(1)]	

Note (1) - exceeds NASA's allocation of 28 kb/s for data transfer on this line.

At the real-time telemetry data rate of 1 kb/s and/or 2 kb/s, only one 7.2 kb/s line is required. At the real-time telemetry data rate of 4 kb/s (the present EOS-A requirement), two 7.2 kb/s lines are required or one of the upgraded 9.6 kb/s lines is required. At the real-time telemetry data rate of 8 kb/s, two 7.2 kb/s or two 9.6 kb/s lines are required. At the real-time telemetry data rate of 16 kb/s or 32 kb/s, the 56 kb/s line is required; however the 32 kb/s real-time data rate would exceed NASA's allocation of 28 kb/s for data transfer on this line.

Near Real-Time Data Transfer for Remote Site to OCC

When on-board computer (OBC) loads (stored commands or data base information) are sent to the spacecraft via the command link, it will be necessary to validate the OBC loads before activation. This will be done by an OBC dump of selected portions of the OBC memory and transfer of this data to the OCC for comparison to the commanded data.

At the NTTF the OBC dump can be transferred in real-time over one of the existing 10 MHz hardlines between NTTF and OCC.

At the Alaska station the 1.32 mb/s link is capable of transferring this data in real time; however, the present NASCOM link to the OCC (2 - 56 kb/s data lines) is not sufficient to handle this data in real-time and buffering at the Alaska station will be required; transfer of the OBC data will approach real-time. Upgrading the link between NASCOM to the OCC to approximately a 200 kb/s data link (to handle the OBC dump rate of 128 kb/s plus the maximum real-time data rate of 37 kb/s at a transfer efficiency rate of 83-1/3%) will remove this restriction.

Although the primary transfer of OBC dump data will be primarily at NTTF and Alaska, capabilities are also required at Goldstone and other remote sites to handle OBC dump data in near real-time. Transfer of the data over the 56 kb/s lines will require site buffering and playback at reduced rates along with the real-time data, previously discussed, in a multiplex mode. The effective rate of transfer of the OBC dump data will be 28 kb/s minus the real-time data transfer rate. At the real-time telemetry rate of 4 kb/s (or 7 kb/s when including tracking data and command status data), the transfer rate for the OBC dump data will be 21 kb/s and require approximately one minute for a full OBC dump of 64K words at 18 bits/word; correspondingly slightly more than two minutes will be required for a real-time telemetry rate of 16 kb/s. If only a portion of the OBC dump is required for verification, the transfer time would be reduced accordingly (i.e., 8K words or 1/8 of the time).

Non Real-Time Data Transfer from Remote Site to OCC

The telemetry dump from the on-board narrow band recorder will be at a rate 20 times the recorded rate for approximately five minutes corresponding to one orbit of recorded data and approximately ten minutes corresponding to two orbits of recorded data. The telemetry dump rate could vary from 20 kb/s for a real-time telemetry rate of 1 kb/s to 640 kb/s for a real-time telemetry rate of 32 kb/s.

At the NTTF the on-board telemetry dump can be handled at the real-time rate over one of the existing 10 MHz hardlines between the NTTF and OCC.

At the Alaska station one mode of operation would be to record the on-board telemetry dump data and playback at the data transfer rate limited by the NASCOM and OCC data link. With the present capability (two 56 kb/s data lines), the present EOS-A on-board telemetry dump rate of 80 kb/s could be handled at the recorded rate requiring either five or ten minutes for the transfer of data corresponding to one or two orbits of recorded data. At the maximum possible on-board dump rate of 640 kb/s the playback rate would have to be reduced to 1:8 and would require 40 or 80 minutes for the transfer of data plus set-up time. The total time period for playback should be limited to prevent infringement on station support requirements.

With the improved 200 kb/s line between NASCOM and the OCC, the on-board telemetry dump rate of 160 kb/s could be handled at the recorded rate. The maximum possible on-board telemetry dump rate of 640 kb/s would have to be reduced to 1:4 and would require 20 to 40 minutes for the transfer of data plus set-up time.

With the present capability between NASCOM and the OCC, the EOS-A on-board telemetry dump rate of 80 kb/s could be handled in real-time. With higher on-board dump rates, data stripping of selected portions of the dump data could be provided for real-time transfer of critical parameters with the remaining data being played back after the pass. Also data compression techniques could be applied at the network stations on the on-board telemetry dump data to reduce the amount of data to be transferred to the OCC if desirable.

At the other remote sites it will be necessary to record the on-board telemetry dump and playback at reduced rates due to the limitation to 28 kb/s of the 56 kb/s line. With the EOS-A on-board telemetry dump rate of 80 kb/s, a playback rate of 1:4 is feasible resulting in playback times of 20 or 40 minutes plus set-up times. On-board telemetry dump rates up to 320 kb/s can be handled in 40 minutes plus set-up time if limited to one orbit of data with full utilization of the 56 kb/s data line.

D. Conclusion

Network Training and Test Facility Interfaces

The utilization of the 10 MHz hardlines presently existing between the NTTF and OCC can handle all the EOS data with no restrictions.

Alaska Station Interface

The 1.32 mb/s data link between the Alaska station and the NASCOM Center is sufficient to handle all the EOS data; the data link between the NASCOM Center, if improved from its present capacity (two 56 kb/s) to 200 kb/s, would provide for real-time transfer of the OBC dump at 128 kb/s or the present EOS-A on-board telemetry dump of 80 kb/s simultaneously with the real-time data.

Other Remote Station Interfaces

Real-time data transfer at the EOS-A present requirements would require two 7.2 kb/s data lines; if these data lines are improved to 9.6 kb/s, only one line is required.

The limitation of 28 kb/s data transfer capacity on the 56 kb/s data lines limits the real-time telemetry data rates to 16 kb/s. This same limitation would limit the playback rates to 160 kb/s for playback times of 40 minutes plus set-up time for one orbit of data.

4.1.4 OPERATIONAL VOICE CIRCUIT COMMUNICATION REQUIREMENTS FOR EOS

Purpose

The purpose of this study was to define the EOS operational voice circuit communication requirements with the remote sites and internal to the OCC.

Summary

Table 4-10 provides a summary of the requirements based on ERTS experience. In addition teletype service to the Low Cost Ground Stations (LCGS) will have to be implemented to enable the LCGS to inform the OCC mission scheduling organization of their coverage requirements and the OCC to brief the LCGS on payload operation over their areas of interest.

TABLE 4-10. OPERATIONAL VOICE CIRCUIT COMMUNICATION REQUIREMENTS

		SCAMA				Closed Circuit Loops (CCL)					PBX	KS	PA System			Other Communi-cations Hardware		
No.	Position	SCAMA 1	SCAMA 2	SCAMA 3	SCAMA 4	Operations Supervisor	Systems 1	Systems 2	Maintenance & Operations	OCC Computer	Private Branch Exchange	Keyboard Send	Access	Area Control	Volume Control	Speaker (Panel)	Headset	Headset
*1	Operations supervisor	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5AR	X	X	A-3	X	X	X	X
2	Command engineer	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X	X	A-3		X	X	X
3	Spacecraft evaluator supervisor	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X				X	X	X
4	Spacecraft evaluator	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X				X	X	X
5	Spacecraft evaluator	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X				X	X	X
6	M&O supervisor	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X	X	A-2		X	X	X
7	OCC/NASCOM terminal	TM	TM	TM	TM	TM			TM	TM	T5	X				X	X	
**8	OCC/NASCOM terminal	SR	SR	SR	SR	TM			TM	TM	T5	X				X	X	X
9	SC&SU	TM	TM	TM	TM	TM			TM	TM	T5	X				X	X	X
10	OCC PCM	M	M	M	M	TM	TM	TM	TM	TM	T5	X				X	X	
11	OCC Computer	TM	TM	TM	TM	TM	TM	TM	TM	TM	T5	X				X	X	
12	Computer maintenance					TM			TM	TM	T5	X				X	X	
13	OCC computer printer	M	M	M	M	TM	TM	TM	TM	TM	T6	X				X	X	
14	Computer PA	M	M	M	M	M	M	M	M	M				A-1	X			
15	Observation area	M	M	M	M	M	M	M	M	M				A-4	X			
16	ETC	TM	TM															
17	GDHS secretary					(Paging Only)					T5R	X	X			X		
18	Offline evaluation					TM	TM	TM	TM	TM	T5	X						

Legend:
- T - Talk
- M - Monitor
- X - Required
- R - Ring
- SR - SCAMA record
- AR - alternate ring
- T5 - 5-position rotary

NOTES:
*Alternate ring as selected from the GDHS secretary position (T4AR).
**OCC-NTTF terminal has dedicated maintenance order circuit to NTTF (ENT).
***A1 through A4 separates the 4 areas within the OCC.

TWX LINE TO ALL LCGS.

4.2 OPERATIONS CONTROL CENTER AND DATA SERVICES ELEMENT DESIGN CONCEPT AND DESIGN/COST TRADEOFFS

4.2.1 PURPOSE AND SUMMARY

The purpose of the study was to:

- Establish a system design concept for the EOS Ground Data Handling System based on EOS requirements and experience gained on the ERTS program, and
- Perform a design/cost tradeoff of viable implementation approaches that satisfy the system concept.

The system design concept for the EOS Ground Data Handling System centralizes the control and monitoring of the ground system within the Data Services Element and utilizes a centralized data base to minimize manual data transfer between the Data Services, Operational Control Center and Image Processing Elements of the ground system.

The design implementation configuration selected employs three medium scale computers and a 24 MB shared disc for the Data Services Element and the Operations Control Center with a direct communications interface between the Data Services Element computer and the Image Processing Element.

4.2.2 REQUIREMENTS AND ANALYSIS

System Design Concept

A study of the ground station processing functions required to support the EOS mission coupled with the experience gained from design, implementation, test, operation and enhancement of the ERTS Ground System has evolved a system design concept for EOS which integrates each entity within the system. The system is designed to meet the following objectives:

- Minimal manual data transfer
- Continual and comprehensive tracking of all data
- Effective management reporting
- Efficient processing of user requests

As depicted in Figure 4-5, each element of the EOS Ground Data Handling System operates through a centralized data base. With this concept, it becomes possible to centralize the ground system control functions in the Data Services Element (DSE) and to design the Operations Control Center (OCC) and Image Processing Element (IPE) on a functional basis. The Data Services Element schedules spacecraft operations, directs all video data processing and product generation, provides accounting and reporting for the entire ground system and serves as the interface with the user community. The DSE is also responsible for the maintenance of the EOS data base and the dissemination of data to the functional sub-elements.

The advantage to this approach is that the subelements are functionally oriented and therefore simpler in design plus offering adaptability for future growth. In addition, data flow between elements is minimized which in turn results in reduced operations costs and increased reliability.

Tables 4-11 and 4-12 provide a summary of the OCC and DSE functions inputs and outputs including those external to the ground system.

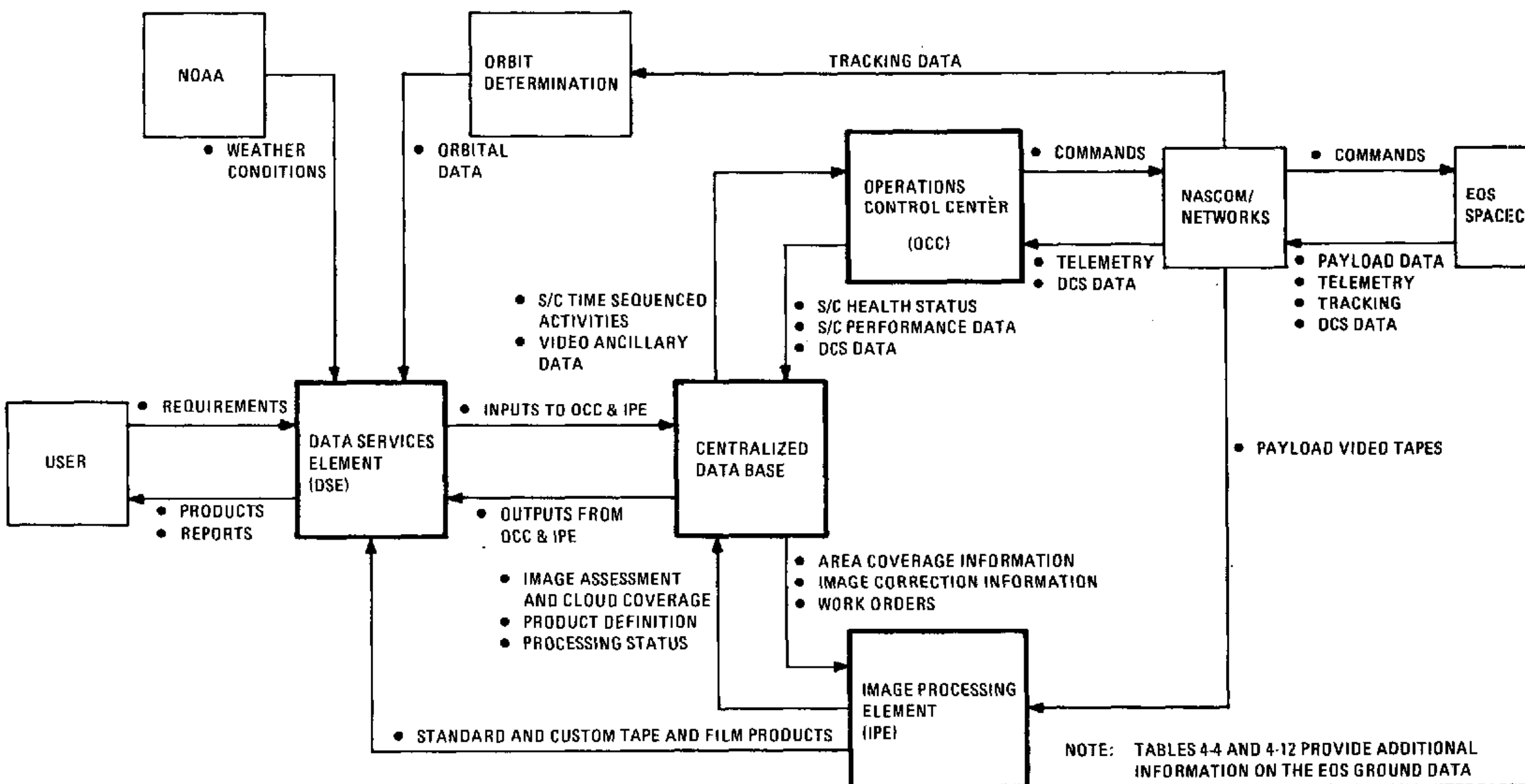


Figure 4-5. EOS Ground Data Handling System

TABLE 4-11. SUMMARY OF OCC FUNCTIONS, INPUTS AND OUTPUTS

Functions	Inputs	Outputs
1. Spacecraft command and control 2. Spacecraft telemetry retrieval and processing 3. Determination of spacecraft health and status 4. Generation of displays and reports 5. Command generation 6. Control remote station contact schedule	<u>From Networks</u> 1. Telemetry data via the NASCOM 2. Data Collection System inputs 3. Voice and teletype communications <u>From DSE</u> 1. System scheduler outputs describing the planned sequence of all spacecraft activities 2. Ground control point information, calibration data and predicted video data formatted for transmission to the spacecraft for inclusion in the video data	<u>To Networks</u> 1. Commands for controlling the S/C 2. Ground point, emphemris, calibration, predicted video and other auxiliary data to be transmitted to S/C for inclusion in video data <u>To DSE</u> 1. Spacecraft and ground station configuration and status as an input for the system scheduling function 2. Spacecraft performance data as to what data was actually acquired 3. Edited System Scheduler outputs 4. DCS data to be used by DSE in generating DCS products

TABLE 4-12. SUMMARY OF DSE FUNCTIONS, INPUT AND OUTPUTS

Functions	Inputs	Outputs
Associated with OCC	From OCC	To OCC
1. Priority Pre-processor 2. System Scheduling 3. Video Support Software 4. DCS Processing 5. File Management	1. Spacecraft and ground station configuration and status as an input for the system scheduling function 2. Spacecraft performance data as to what data was actually acquired 3. Editing of System Scheduler outputs 4. DCS data to be used by DSE in generating DCS products	1. System scheduler outputs describing a time sequence of all spacecraft activities 2. Ground control point information, calibration data and predicted video data formatted for transmission to the spacecraft to be included in the video data
Associated with IPS	From IPS	To IPS
1. Pre-processing Software 2. HDDT Generation Software 3. Production Control Software 4. File Management	1. Actual video tape content including image assessment and cloud cover data 2. HDDT information describing the contents of each HDDT 3. Product reporting describing all products produced and archieval information 4. Processing information to maintain a comprehensive accounting system which will identify processing time lines and problem areas.	1. Predicted content of the video tape during initial processing 2. Ground control points, best fit empherial data and calibration data during the processing of data to HDDT's 3. Work orders and shipping orders to control the processing of all IPE products 4. Index of all archieval data so as to easily identify the location of imagery during production processing
Associated with User Community	From User Community	To User Community
1. User Support Software 2. Management Reports 3. File Management 4. Browse	1. User Requirements both standing order and retrospective 2. User priority information	1. Available coverage and products 2. User requirement status including historical information 3. Work order status
Associated with Management	From Management	To Management
1. Management reports 2. File management 3. Priority Pre-processor 4. User support software 5. Production control software	1. Special priorities on production processing 2. Special priorities on acquisition	1. Total accounting of all EOS activities 2. Production status 3. User requirement status 4. Problem identification
Additional Functions	Additional Inputs	
1. File Management	1. Weather conditions from NOAA 2. Orbital data from ODG	

4.2.3 DESIGN IMPLEMENTATION ALTERNATIVES CONSIDERED

Identification of Alternatives

Three design implementation alternatives to satisfy the system concept for the EOS Ground Data Handling System were considered. They are as follows:

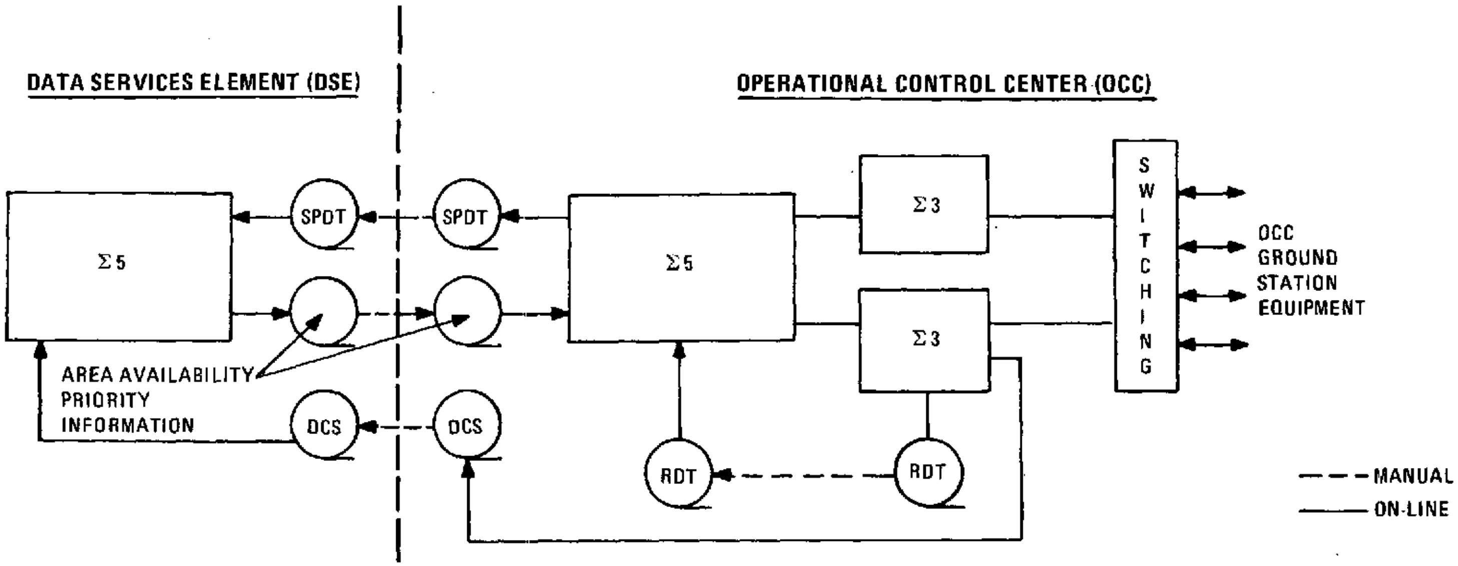
- Upgrade ERTS configuration with existing OCC and DSE ADPE (Alternative I),
- Upgrade ERTS configuration with new OCC and DSE ADPE (Alternative II), and
- New design configuration with new OCC and DSE ADPE (Alternative III).

In all three alternatives the centralized data base concept is employed. This is advantageous since it provides a common data base for all functions and reduces the amount of storage each would have on an individual basis since identical information is required at several areas. In addition, and probably most important, this concept permits effective management control and optimal tracking of problems as well as products.

A direct interface between the Data Services Element and the Image Processing Element is a requirement. This interprocessor link is dependent upon the data transfer rate and the distance between equipments and may be in the form of a data interchange at a common bus or it may be by communication channel of EIA RS-232C definition.

Definition of Alternative I

Since the EOS requirements are similar to those of ERTS, modification of the present ERTS facility is an obvious possibility. Figure 4-6 is a block diagram of the present ERTS OCC and DSE ADPE; Figure 4-7 is a block diagram of the upgraded ERTS configuration. The hardware required to upgrade the present configuration is estimated to cost approximately $450K. The software modifications and additions are estimated to be a 32.1 man-year effort for this alternative.



Σ5 (DSE)

1 – 84K CORE
1 – 79 MB DISC
8 – 9 TRACK MAG. TAPES
2 – 7 TRACK MAG. TAPES
1 – LINE PRINTER
2 – CRT's
1 – CARD READER
2 – TTY's
1 – CARD PUNCH

Σ5 (OCC)

1 – 84K CORE
1 – 30.2 MB DISC
4 – 9 TRACK MAG. TAPES
2 – LINE PRINTERS
1 – CARD READER
1 – CARD PUNCH
6 – CRT's

Σ3

2 – 32 CORES
2 – 9 TRACK MAG. TAPES
1 – CARD READER
1 – CARD PUNCH

Figure 4-6. Present ERTS OCC and DSE ADPE

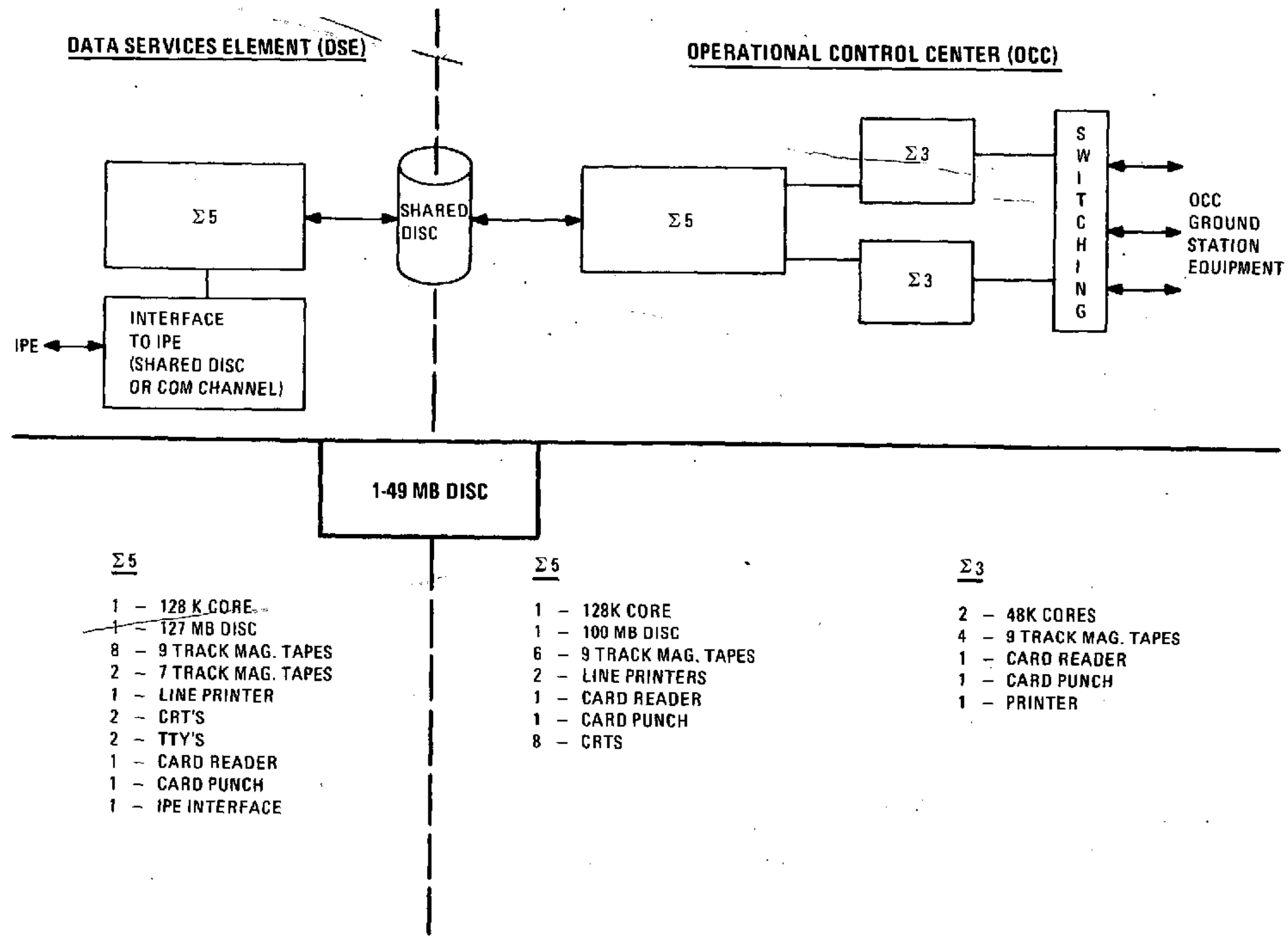


Figure 4-7. Upgraded ERTS Configuration with Existing OCC and DSE ADPE (Alternative I)

Definition of Alternative II

This alternative maintains essentially the same functional alignment and configuration of the first alternative but introduces new computers and applicable software to satisfy the EOS requirement. The block diagram of this alternative is shown in Figure 4-8. An upward compatible computer to the present ERTS system was considered as the basis for approximating costs for Alternative II and III. The hardware costs for configuration II is estimated to be $1.89 million; the software modifications and additions are estimated to be a 50.5 man-year effort.

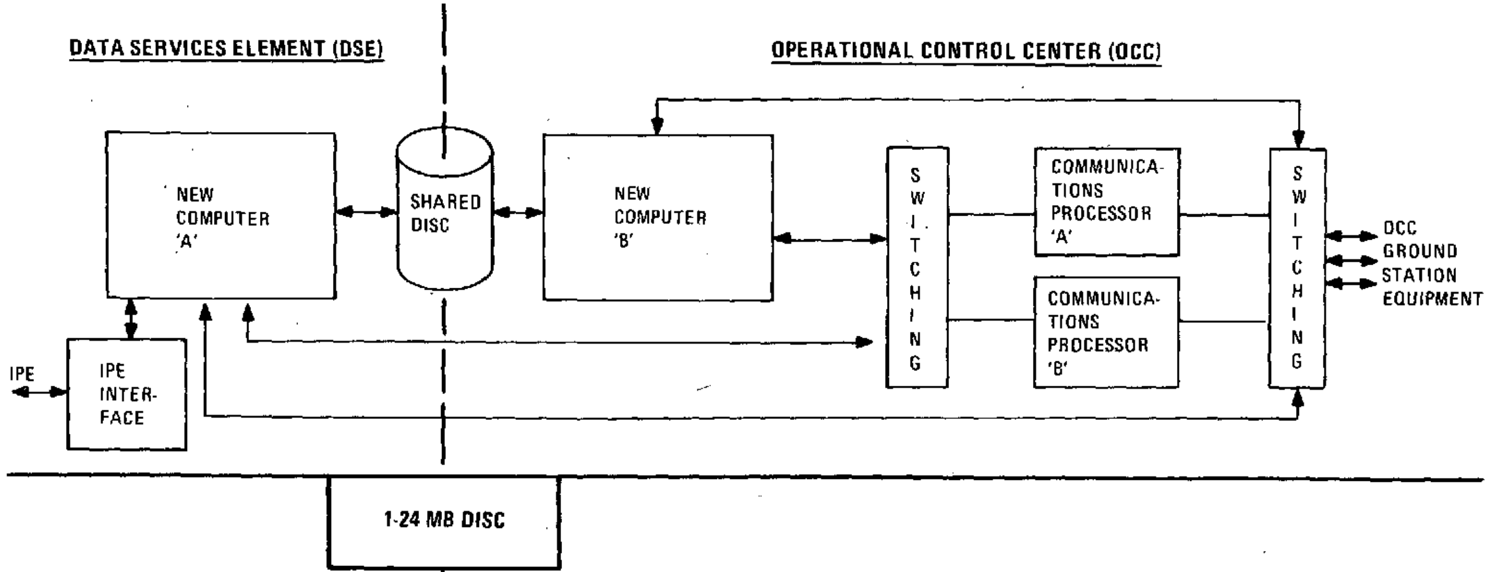
Definition of Alternative III

This alternative replaces the communication processors and large computer of the second alternative with two medium scale computers; the DSE facility remains the same as in the second alternative. The block diagram of this alternative is shown on Figure 4-9. The hardware costs and software costs are approximately the same as the second alternative ($1.91M and 47.5 man-years).

4.2.4 DESIGN/COST TRADEOFF

Tradeoff Criteria and Data

The design implementation alternatives described above were evaluated with respect to hardware and software cost, development risk, reliability, maintainability, performance and schedule constraints. Table 4-13 summarizes the salient characteristics for each alternative. The special purpose OCC ground station functions and equipment are not included here since all the alternative designs will accommodate either the present ERTS design or a new design.



1 – CPU 6 us LAS TIME PROCESSOR
1 – 128 K CORE
1 – 11 MB DISC
1 – 200 MB DISC
8 – 9 TRACK MAG. TAPES
2 – 7 TRACK MAG. TAPES
2 – LINE PRINTERS
1 – CARD READER
1 – CARD PUNCH
2 – COMMUNICATION CONTROLLERS
1 – IPE INTERFACE

1 – CPU 6 us LAS TIME PROCESSOR
1 – 128 K CORE
1 – 11 MB DISC
1 – 100 MB DISC
8 – 9 TRACK MAG. TAPES
2 – LINE PRINTERS
1 – CARD READER
1 – CARD PUNCH
3 – COMMUNICATION CONTROLLERS
8 – CRT's

2 – COMMUNICATION PROCESSOR (CPU + 48K CORE)
2 – 9 TRACK MAG. TAPES
1 – PRINTER
1 – CARD READER
2 – SWITCHING UNITS

Figure 4-8. Upgraded ERTS Configuration With New OCC and DSE ADPE (Alternative II)

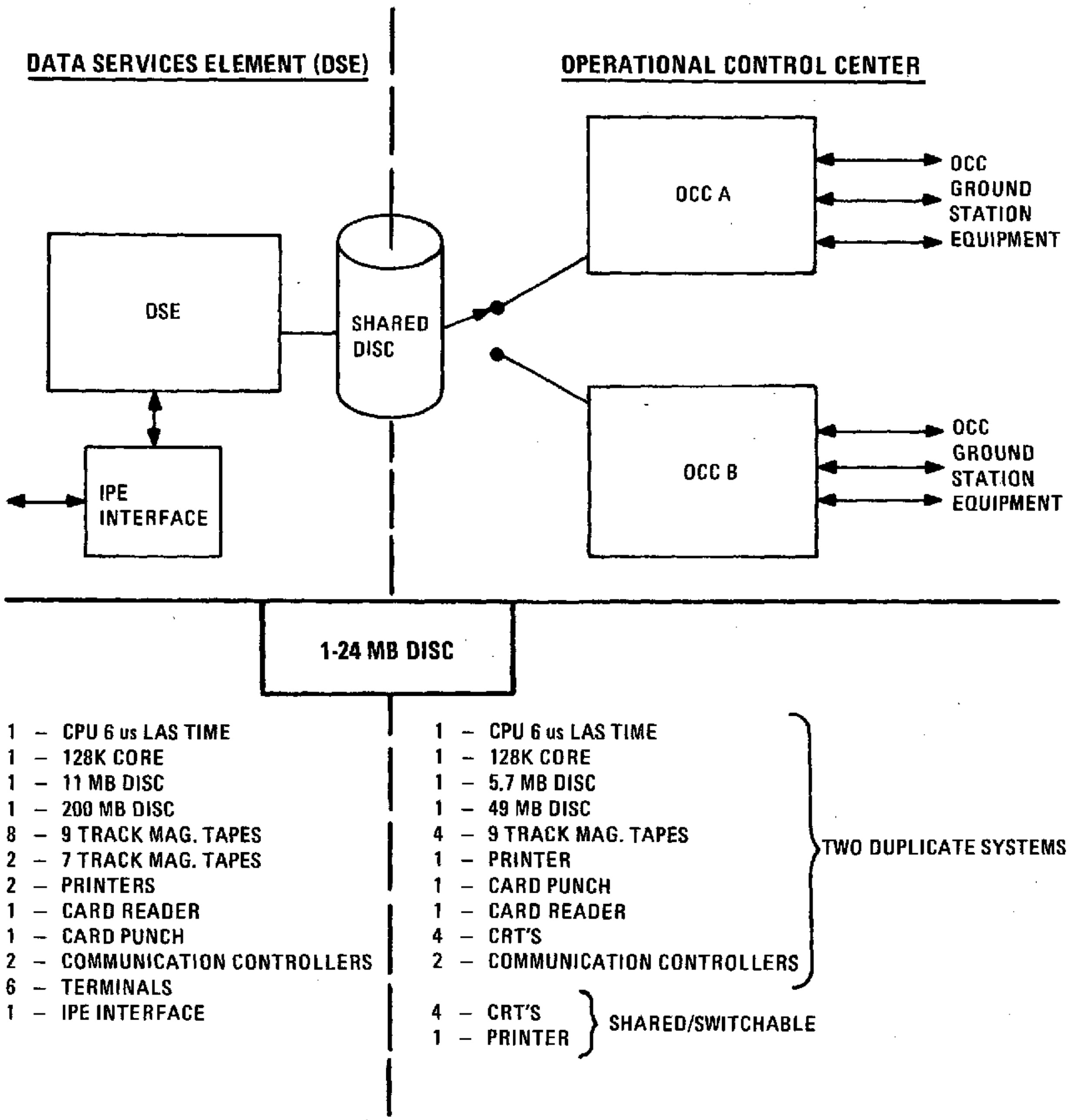


Figure 4-9. New Design Configuration With New OCC and DSE ADPE

TABLE 4-13. COMPARISON OF ALTERNATIVES AGAINST TRADEOFF PARAMETERS

Alternatives	Alternative I	Alternative II	Alternative III
Tradeoff Parameters	Upgraded ERTS Configuration with existing OCC and DSE ADPE	Upgraded ERTS Configuration with new OCC and DSE ADPE	New Design Configuration with new OCC and DSE ADPE
Cost - Hardware (Computer and Peripheral) - Software	0.45 M 32.2 Man Years	$1.89 M 50.5 Man Years	$1.91 M 47.5 Man Years (Can be reduced for initial single vehicle operation)
	Lowest	High	High (Equal to Alt. II)
Development Risk	• Operating System no longer being improved • Present Operating system does not support full multi vehicle programming • Existing design with modification • Maximum core size 128K	• Current operating system will receive full operating system support • Existing concept with modifications (more than alternate I)	• Current operating system will receive full operating support • New concept
	Marginal	Acceptable	Acceptable but higher than Alternate II
Reliability	• Old equipment-lower reliability • Degraded back up mode capability	• New equipment-higher reliability • Degraded backup mode capability	• New equipment-higher reliability • Full back up capability
	Marginal at Best	Acceptable	Best
Maintainability	• Out of production by 7 years by EOS launch date (parts and services potential problem) • Operating system (BPM/BTM) no longer being improved by XDS	• Current equipment will receive full hardware and software support	• Current equipment will receive full hardware and software support • Both OCC computers use same software; lowest software maintenance cost
	Unacceptable	Acceptable	Best
Performance Constraints	• Inability to support more than one vehicle in proficient manner • Limits improvements in design from ERTS experience	• Can provide non-simultaneous multi-spacecraft support • Improvements in design from ERTS experience possible	• True multi-vehicle support • Improvements in design from ERTS experience possible
	Marginal	Acceptable	Best
Schedule Constraints	• Software development and hardware upgrade constrained by present utilization of equipment on ERTS	• New equipment - not constrained by existing programs	• New equipment - not constrained by existing programs
	Serious Potential Problem	No Problem	No Problem

Significant Characteristics of Alternative I

This design alternative, based upon a viable time proven system, offers the lowest initial cost. However, this is offset by the prospect of developing and maintaining a system that, by launch date, will have been out of production for seven years. Much higher recurring costs for parts and maintenance may also be anticipated in this situation. The system's limited expandability, degraded back-up mode of operation and inability to support more than one vehicle in a proficient manner make it the least desirable design for EOS support. In addition, this alternative could be subject to serious schedule constraints due to utilization on the ERTS program.

Significant Characteristics of Alternative II

In this case, relatively high cost of new equipment is offset somewhat by the greater capabilities of the system. It will be a more economical and reliable operation and since it will be the current line of the computer vendor, it will receive the full hardware and software support that a discontinued system would not. Setting up this system configuration would allow the use of many of the techniques proven to be successful on the ERTS project, while still providing the opportunity to expand and improve upon it. This system still has the drawbacks of the degraded backup mode of operation and inefficient multi-vehicle support.

The cost of developing all new software can be considerably mitigated by adapting a large portion of the current ERTS software (the major portion is written in FORTRAN) to the EOS design.

Significant Characteristics of Alternative III

This alternative is the most appropriate design solution for the EOS system. It provides for full backup and true multi-vehicle support. A reduced initial configuration may be used, to help reduce initial program costs, until a second vehicle is to be supported.

The same pertinent remarks about the software as stated for II may be made here, plus the fact that this design results in only one operating system to maintain. The fact that the costs for alternatives II and III are roughly equivalent leaves little doubt that III, with its major advantages over II, is the proper choice.

The apparently high initial cost is counterbalanced to a great degree by the increased number of years that the system will be serviceable.

4.2.5 RECOMMENDED DESIGN APPROACH

Alternative III presents a viable solution to the EOS design problem. This approach is recommended because it best suits the common data base concept for all functions supporting the EOS mission. The hardware configuration allows the development of the best software system. The flexibility offered for software design is illustrated by such possibilities as operating like a dual processor system or interconnecting all computers thru shared discs. This also allows for greater expandability than the other configurations as well as greater adaptability for future multi-mission support.

4.3 IMAGE PROCESSING ELEMENT DESIGN CONCEPT AND DESIGN/COST TRADEOFFS

4.3.1 PURPOSE AND SUMMARY

The purpose of the study was to:

- Establish a requirements baseline for the Image Processing Element (IPE) as well as requirement ranges and alternates to permit intra-Image Processing Element design/cost tradeoffs and to support higher level EOS system design/cost tradeoffs discussed in Section 2.0 of this report,
- Establish a design concept for the IPE which places emphasis on information flow and equipment implementation within the element,
- Perform design/cost tradeoffs, on viable implementation approaches for the IPE, and
- Provide parametric cost/performance data to be utilized by NASA in the finalization of the IPE requirements.

Baseline Requirements and Alternatives

The baseline requirements were established for the overall IPE and then allocated to the major subsystems within the element.

System throughput is the major cost driver to the IPE; the two major system throughput ranges, identified in NASA's "Specification for EOS System Definition Studies," were included in the requirement ranges. The system throughput ranges are:

- 40 to 250 scenes/day/sensor for the digital image correction function with the baseline at 40 and benchmarks at 100, 175 and 250 scenes/day/sensor for establishing parametric cost/performance data, and

- 20 to 200 scenes/day/sensor for the film image generation function with the baseline at 20 and benchmarks at 40, 75, 100, 150, 175 and 200 scenes/day/sensor.

In support of higher level EOS system design/cost tradeoffs, three major requirement alternatives were identified in order to determine their impact on the IPE. They are:

- The various HRPI and TM instrument concepts.
- 0 to 60% oversampling of the TM instruments, and
- Instrument reformatting function performed on the spacecraft.

Two major requirement alternatives, which impact only the IPE were identified. They are as follows:

- Resampling Technique (nearest neighbor or bilinear interpolation vs. $\frac{\sin x}{x}$) and
- Map Projection (UTM vs. Space Oblique Mecator)

Design Concept

The functional design concept, established for the IPE is to include in the video stream on the spacecraft all the necessary ancillary data that is required to both radiometrically correct the instrument data and to geometrically correct the data to 450 meter accuracy. This minimizes information flow between ground system elements at the time of initial processing and thereby improves the system throughput.

The design concept, established for the IPE, is configured to provide a standard on-line processing function (preprocessing and image correction function of all valid data) and custom off-line processing function (selected data/film on request).

The standard on-line processing function is divided into a two pass system. The first pass is performed at approximately real-time data rates and is for the purpose of screening the data and extracting all the necessary information to perform the radiometric and geometric correction functions. The second pass is to perform the image correction functions, generate a HDDT of the corrected data and to provide information to the Film Image Generation Subsystem so it can produce a film strip of one band from each instrument for cataloging purposes. The two pass concept was selected since the actual image correction of the data is more costly and slower to perform than is the preprocessing function and system throughput could be maximized by the elimination of unusable data and tape gaps from the image correction processing line.

The custom off-line processing function is subdivided into three independent subfunctions which can be executed simultaneously. These are a digital tape generation function, a film image generation and processing function and a combined extractive processing/browse file function. The similarities in equipments needed to satisfy the extractive processing and browse requirement led to a combination of these functions into a single subsystem.

Design/Cost Tradeoffs

The major design/cost tradeoff for the standard on-line functions was associated with the selection of the implementation approach for the Digital Image Correction Subsystem. Four different system configurations were designed, evaluated and costed for three generic configurations. The general purpose computer approach, studied by IBM, was eliminated on the basis of costs. The flexible processor approach, studied by CDC, is the highest in cost of the other three configurations and quite cost sensitive to increased throughput. The micro-programmable processor approach, studied by IBM, and the special purpose processor approach, studied by GE, are the viable candidates; the cost difference vary from 600K to 900K, depending on throughput, in favor of the latter. The tradeoff of cost vs. flexibility of these two approaches will continue.

The resampling technique employed proved to be relatively insensitive to the IBM micro-programmable processor approach and the GE special purpose processor approach (reduction of \$20 to \$50-K in changing to nearest neighbor vs. the baseline $\frac{\sin x}{x}$ re-sampling approach).

The cost impact of implementing the UTM projection alternative (due to the storage of data necessary to account for the maximum rotation angle between the input scan line and the output grid line) was in the range of $250 to $300K for all three configurations. Based on the anticipated throughput requirement of ~6 scenes/day for UTM projection data, performing the transformation function off-line has a decided cost advantage ($75K vs. $300K).

The major design/cost tradeoff for the custom off-line function was associated with the implementation approach for the film image generation system. Two implementation configurations were studied. The first configuration dedicated a laser beam image recorder to perform the standard on-line catalog film generation with a number of laser beam image recorders to generate the custom off-line film images from HDDT's generated in the standard on-line function. The second configuration utilized an intermediate HDDT preprocessing system to generate an efficiently packed HDDT for processing by the film image generation system to maximize the efficiency of the more expensive laser beam image recorders. At a low system throughput rate of 20 scenes/day/sensor, the costs are about the same but the second alternative becomes the preferred approach as the system throughput is increased. A cost advantage of $1.3M exists at the high system throughput rate of 200 scenes/day/sensor.

Parametric Cost/Performance Data

Parametric cost/performance data has been generated for the standard on-line and the three custom off-line functions. Table 4-14 summarizes the IPE Equipment costs as a function of combined standard on-line system throughput rates and custom off-line system throughput rate.

TABLE 4-14. IPE EQUIPMENT COSTS AS A FUNCTION OF COMBINED SYSTEM THROUGHPUT RATES

IPE Equipment \ Standard On-Line System Throughput (scenes/day)	40	100	175	250
Custom Off-Line System Throughput (scenes/day)	20	75	125	200
On-Line Function				
• Digital Image Correction	2. 2	2. 4	2. 9	3. 1
Off-Line Functions				
• HDDT Generation	0. 1	0. 2	0. 3	0. 4
• CCT Generation	0. 3	0. 3	0. 4	0. 5
• Film Generation	0. 7	1. 4	1. 7	2. 7
Total	$3. 3M	$4. 3M	$5. 3M	$6. 7M

In support of the higher level EOS system level design/cost tradeoffs the cost impact of the following requirement alternatives were established:

- Instrument reformatting function performed on the spacecraft
  - Transfer of this function to the S/C would reduce the cost of the Digital Image Correction Subsystem $100K but add substantial cost to the spacecraft; therefore, it was determined to perform this function on the ground.
- Instrument Approaches
  - The Te-Gulton Thematic Mapper and HRPI instruments have the lowest impact on the Digital Image Correction Subsystem. The Honeywell Thematic Mapper and HRPI Instruments have the greatest impact due to the additional storage required to linearize the conical scan format; the cost differences between the two instrument approaches is about $300K.
- Oversampling of the Thematic Mapper Instruments
  - The cost impact on the Digital Image Generation Subsystem of reducing the oversampling of the Thematic Mapper Instruments from 40% to 0% is

in the range of \$200 to \$300K due to an effective 15% decrease in total input data rate.

4.3.2 REQUIREMENTS

Introduction

The purpose of the Image Processing Element is to process and correct both HRPI and Thematic Mapper Instrument data contained on video tapes and provide output products in the form HDDT's, CCT's, film, prints, thematic maps, etc. All processing and correction of the data will be accomplished in the digital domain to achieve the desired output product accuracy requirement and to satisfy the needs of a user community that performs digital extractive processing to derive resource management information from the data.

The system level error allocations (discussed in Section 2.16) define the characteristics of the input data while the system performance requirements (also discussed in Section 2.16) define the quality of the output products. These two sets of requirements plus those discussed in this section provide the specifications for the performance of the IPE.

Sensors

The three Thematic Mapper and four HRPI instruments listed below were all considered in the design/cost tradeoffs in the IPE:

- Thematic Mapper
  - Hughes (object plane scan)
  - Te-Gulton (linear image plane scan)
  - Honeywell (conical image plane scan)

- HRPI
  - Westinghouse (linear array)
  - Hughes
  - Te-Gulton
  - Honeywell

The Hughes Thematic Mapper and the Westinghouse HRPI were selected as the reference sensors. The deltas in cost and performance on the ground system due to the other sensors were identified.

Input Data Format

The format of the input data has a considerable impact on the cost and complexity of the IPE. The format is determined primarily by the sensor focal plane configuration and the data sampling and multiplexing strategy employed in the MOMS. The baseline input data format is summarized below:

- TM and Scanning HRPI Data
  - Serial Data Stream
  - Spectrally Interleaved
  - Band-to-Band Offsets up to 40 words between bands with integral spacing. (up to 2 lines for Band-7 in Honeywell TM)
  - Non-Integral Pixel Offsets per Detector within a band
- HRPI Data (Linear Array)
  - Serial Data Stream
  - Spectrally Interleaved
  - Band-to-Band Registered
  - Non-Integral Pixel Spacing
  - Two Line Delay Due to Staggered Linear Array

In addition, the alternate format listed below was considered to determine the cost differential in the ground station. Since the same reformatting functions must be performed by all stations receiving the sensor data, a cost trade was made between ground processing (many times) and on-board processing (one time) to reformat the data.

- TM and HRPI
  - All Data Band-to-Band Registered for TM
  - Two Line Delay Removed in HRPI
  - Non-Integral Pixel Spacing Removed from HRPI

A reformatting function must be performed to compensate for the multiplexing strategies and various sensor configurations which produce a serial data stream that has non-optimum pixel arrangements. For example, the output format must be band-to-band registered, spectrally interlevered, and linearized (all pixels along a straight line in sequence).

Input Data Rate

The received data rates and information rates of the various instruments are not the same primarily due to the multiplexing scheme employed and the scan inefficiencies. The baseline received data rate for the Thematic Mapper assumed a 40% oversampling requirement at the input and output of the Digital Image Correction Subsystem with a specified range from 0 to 60%. The baseline input data rate for the HRPI assumed a 0% oversampling. The resulting range of information data and ancillary data rates are shown in Table 4-15.

TABLE 4-15. INPUT DATA RESULTS

Sensor	Information plus Ancillary Input Data Rate	Information Data Rate		
		Minimum	Baseline	Maximum
TM	$\leq$120 Mb/s	~60 Mb/s @ 0% oversampling	~84 Mb/s @ 40% oversampling	~96 Mb/s @ 60% oversampling
HRPI	$\leq$120 Mb/s	—	~90 Mb/s	—

Throughput Range and Available Processing Time

The system throughput considered the range from 40 to 250 scenes per day of both Thematic Mapper of HRPI data. A scene is defined as a 185 Km long segment (approximately 25 seconds of real time data) by 185 Km wide segment for the Thematic Mapper or by 48 Km wide or larger (depending on the pointing angle) for the HRPI.

The system throughput is a major cost driver for the Image Processing Element. The discrete processing loads listed below were used as benchmarks in the design/cost trades:

- 40 scenes/day - This is the minimum system throughput to be considered and is equivalent to real-time coverage of the United States using one spacecraft.
- 100 scenes/day - This is the system throughput equivalent to all real-time coverage from one spacecraft and the three receiving stations (Goldstone, Alaska and NTTF) over all available land mass.
- 175 scenes/day - This is the approximate system throughput experienced with the ERTS system for one spacecraft with onboard tape recorders.
- 250 scenes/day - This is the maximum system throughput to be considered and is roughly the maximum number of scenes that operationally can be collected using one spacecraft with two 15 minute on-board tape recorders.

The available processing time of 40,000 seconds/day, 7 days per week, is based on a 16 hour day at approximately 70% efficiency.

Quality Assessment

An assessment of the received data is necessary to identify regions of valid data, determine characteristics for data cataloging and for future processing scheduling.

Parameters to be determined include data quality (i. e., bit error rate), cloud cover and failed detectors related to tape area.

Radiometric Correction

All data, regardless of the geometric accuracy, will be corrected to the same excellent radiometric accuracy. EOS A requirements on the output product radiometric accuracy are not major cost drivers in the Central Data Processing Element. The approach is to have all information necessary to calculate this correction included in the data stream. This data is:

- Internal calibration lamp data utilized to remove detector banding and short term instability,
- Sun calibration data provided to remove long term instabilities,
- Failed detector compensation required, and
- Video histogram analysis applied if necessary (a cost tradeoff with calibration lamp approach).

Geometric Correction

A major cost driver to the Digital Image Correction Subsystem is the stringent geometric accuracy requirements. All output data will have a geometric accuracy falling into one of the following categories:

- Uncorrected Data - 450 Meter Accuracy
  - Utilizes Predicted Ephemeris
  - Performs X Correction of Each Scan Line (line length, earth rotation, scanning/sampling/array non-linearities, earth curvature and best fit planar projection)
  - All Data Linearized to Straight Lines

- Uncorrected Data - 170 Meter Accuracy
  - Utilizes Best Fit Ephemeris
  - Performs X Correction on Each Scan Line (same as uncorrected data - 450 meter accuracy)
  - All Data Linearized to Straight Lines
- Corrected Data - 15 Meter Accuracy
  - Utilizes Best Fit or Predicted Ephemeris
  - Performs X, Y Correction of all Error Sources
  - Uses Ground Control Points (GCP's) To Model Errors
  - Data Presented in Specified Map Projection
  - Data Grided with Respect to the Earth

Resampling

Due to uncertainty in the user community as to the desirability of one resampling technique as opposed to another, the Digital Image Correction Subsystem was specified to have the resampling capabilities for nearest neighbor, bilinear and sin x/x (cubic approximation). The baseline system is designed for 100% data throughput with the cubic approximation to sin x/x. The cost differences for 100% nearest neighbor and 100% bilinear resampling were determined to define the range of system complexity and cost to perform resampling.

HDDT Generation

The Digital Image Correction Subsystem produces both resampled and not-resampled HDDT's of the data received. The resampled HDDT is copied and shipped to major data users. The resampled HDDT master will be archived and utilized in the custom processing function. The non-resampled HDDT will also be archived along with the derived correction information data and utilized in special custom processing functions requiring different projection and/or resampling contained on the resampled HDDT.

Computer Compatible Tape Generation

The purpose of this function is to produce computer compatible tapes from HDDT's or film and perform custom processing of the data. The throughput is assumed to be a maximum of 35 scenes/day. An illustrative listing of the custom processing to be provided is:

- Digital Enlargement
- MTF Compensation
- Resolution Reduction
- Area Reduction
- Custom Projection
- Pixel Reformatting

Film Image Generation and Processing

The system must have the capability to produce up to 200 scenes/day of first generation B&W products and 100 scenes/day of second generation color products. The options available for custom processing are the same as those listed for CCT generation with the addition of the following:

- Photographic Gama Change
- False Color Mixes
- Photo Copying
- Photo Enlargement

The system shall also have the capability to produce, for cataloging purposes, a film strip of a selected channel from each sensor of the data contained on the resampled HDDT's provided to the major data users. The film strip will be copied and included with the shipment of the HDDT's as well utilized for archiving.

Browse Facility

The system will provide a capability for investigators to access and view the archived data. Since the primary storage medium is the HDDT, the Browse Facility will provide a video display capability; also this function will provide the capability of viewing the catalog film identified above.

Extractive Processing

An extractive processing option has been provided which is capable of converting corrected EOS multispectral image data into user-oriented parametric information such as the identification and classification of agricultural crops, urban areas, etc. The implementation system is interactive and has the capability of performing the following functions:

- Feature selection/extraction: obtaining the features or characteristics of the scene which can be used to identify points or objects in the scene.
- Feature reduction: a linear transformation of the features obtained above to gain a minimum optimal set of features which will be sufficient to identify objects or points in a scene.
- Feature classification/estimation: the conversion of feature measurements into user oriented parameters (i. e. , corn yield, soil moisture, etc.)

4.3.3 DESIGN CONCEPT

Introduction

In order to satisfy the Image Processing Element requirements and functions, the design concept illustrated in Figure 4-10 has been selected as the baseline. The design concept is configured for standard on-line processing functions and custom off-line processing functions. The preprocessing and image correction functions (consisting of data reformatting, quality assessment, radiometric and geometric correction, initial resampled and not-resampled HDDT generation and film generation for cataloging purposes) are performed on all valid data and are considered as standard on-line processing functions. The remaining functions are considered as custom off-line processing functions since they are performed only on selected data on request.

The information flow within the Image Processing Element has been found to have a major effect on the cost of the element and will be the subject of the bulk of the discussion in this section and the hardware implementation design/cost trades in the following sections.

4.3.3.1 Standard On-Line Processing

Introduction

The standard on-line processing function is divided into a two pass system - pass 1 performs the preprocessing functions and pass 2 performs the image correction functions. Since the system throughput combined with the stringent geometric accuracy requirements are major cost drivers in the subsystem, the baseline design has been configured to insure that the system will provide the necessary output product accuracy and minimize total system costs. Table 4-16 provides a summary of the baseline preprocessing and image correction functions.

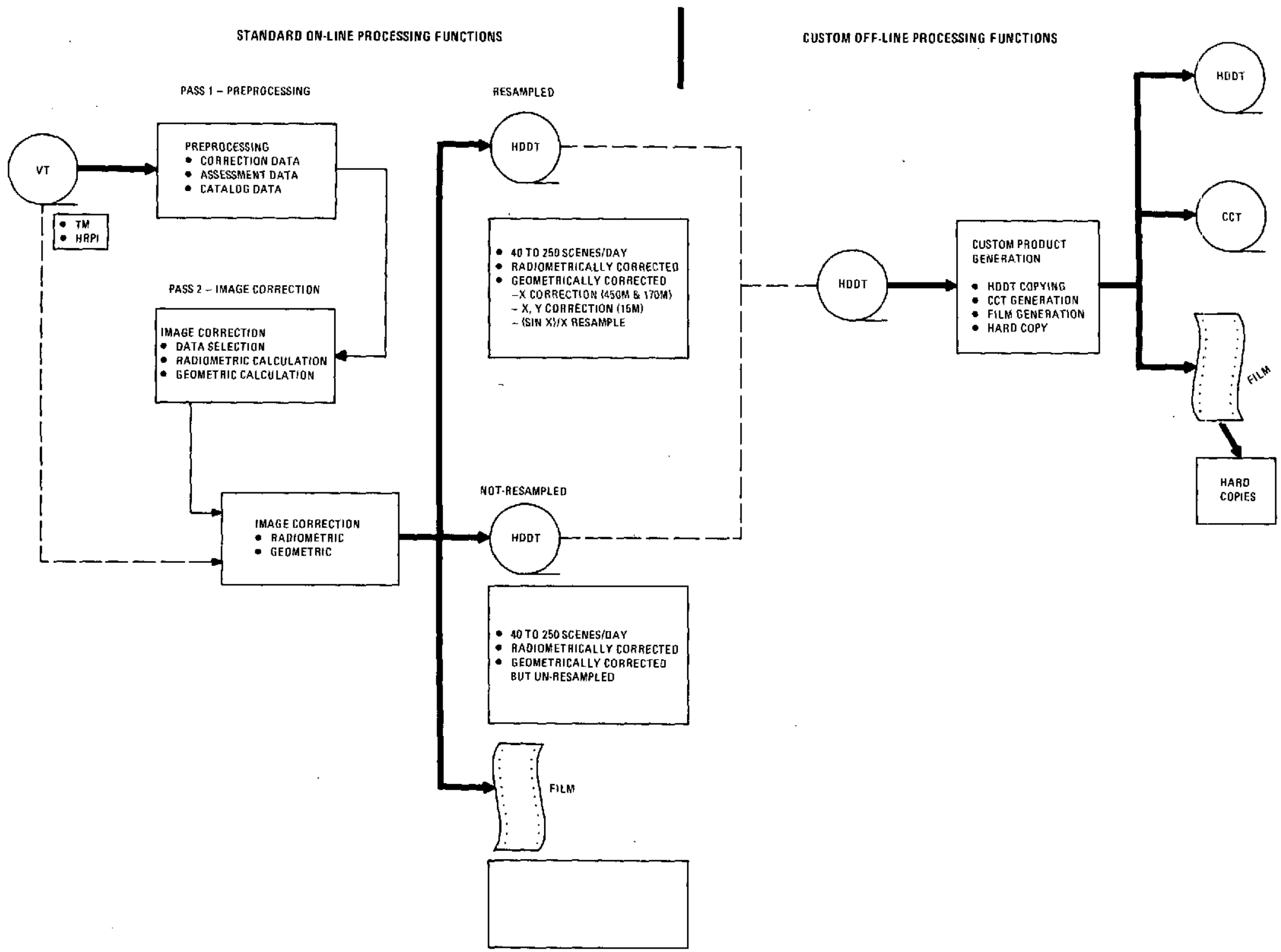


Figure 4-10. Image Processing Element Design Concept

TABLE 4-16. STANDARD ON-LINE PROCESSING FUNCTIONS

Input	Function	Throughput	Output Product
Video Tape (Pass 1)	Quality Assessment - Quality - Cloud Coverage Assessment - Area Specification - Failed Detector Identification	40 to 250 Scenes/Day	Quality Assessment Data to Data Services Element (DSE) for Work Order Generation and Cataloging
Video Tape (Pass 2)	Data Reformatting	40 to 250 Scenes/Day	HDDT's (Resampled) - Master to Archive for Later Use in Generation of Custom Products - Copies Produced Off-Line to Major Users HDDT's (Not Resampled) - Master to Archive for Later Use in Generation of Custom Products requiring different Re-sampling Techniques and/or Projections Film (Catalog) - Master to Archive for Later Use by the Browse Facility - Copies Produced Off-Line to Major Users
	Radiometric Correction	40 to 250 Scenes/Day	
	Geometric Correction		

Position Accuracy	Correction	Projection	Resampling	Throughput
450 M	X	Best Fit Planner	(Sin x)/x	Up to 210 Seconds/Day
170 M	X	Best Fit Planner	(Sin x)/x	
15 M	X and Y	Oblique Mercator	(Sin x)/x	40 Scenes/Day (U. S. Data)
15 M	X and Y	Not Resampled	Not Resampled	40 Scenes/Day (U. S. Data)

Pass 1 - Preprocessing Description

The first pass through the data in the Digital Image Correction Subsystem is performed at approximately real-time data rates and is primarily for the purpose of screening the data and extracting all the necessary information to perform the radiometric and geometric correction.

A functional flow diagram of the first pass preprocessing function is shown in Figure 4-11. The data stripping and timing modules perform basic functions of stripping and buffing timing data, quality assessment indicators, calibration data, ground control point areas, and ancillary data which has been inserted into the video stream on the spacecraft. The ancillary data includes sun calibration data, predicted ephemeris, rate and position attitude data, timing updates, alignment information and assessment information.

This data is all that is necessary to radiometrically correct the data and to geometrically correct the data to 450 meter accuracy. The ancillary data, assessment data, ground control point areas, and cataloging information is stored on a disc for all data on the video tape. The video data is reformatted and presented on an image display to allow an operator to assist in data assessment and ground control point area selection. An HDDT is not generated normally during this pass but one can be produced at a slower processing rate if a quick look at the data is desired.

Pass 2 - Image Correction Description

The functional flow of the second pass through the data is depicted in Figure 4-12. During the rewind of the Video Tapes in preparation for the second pass, the control and evaluation module utilizes the results of the first pass to calculate geometric correction data plus the radiometric correction data based on the ancillary data contained in the video data, as well as the areas of valid data to be processed. Since the actual image correction of the data

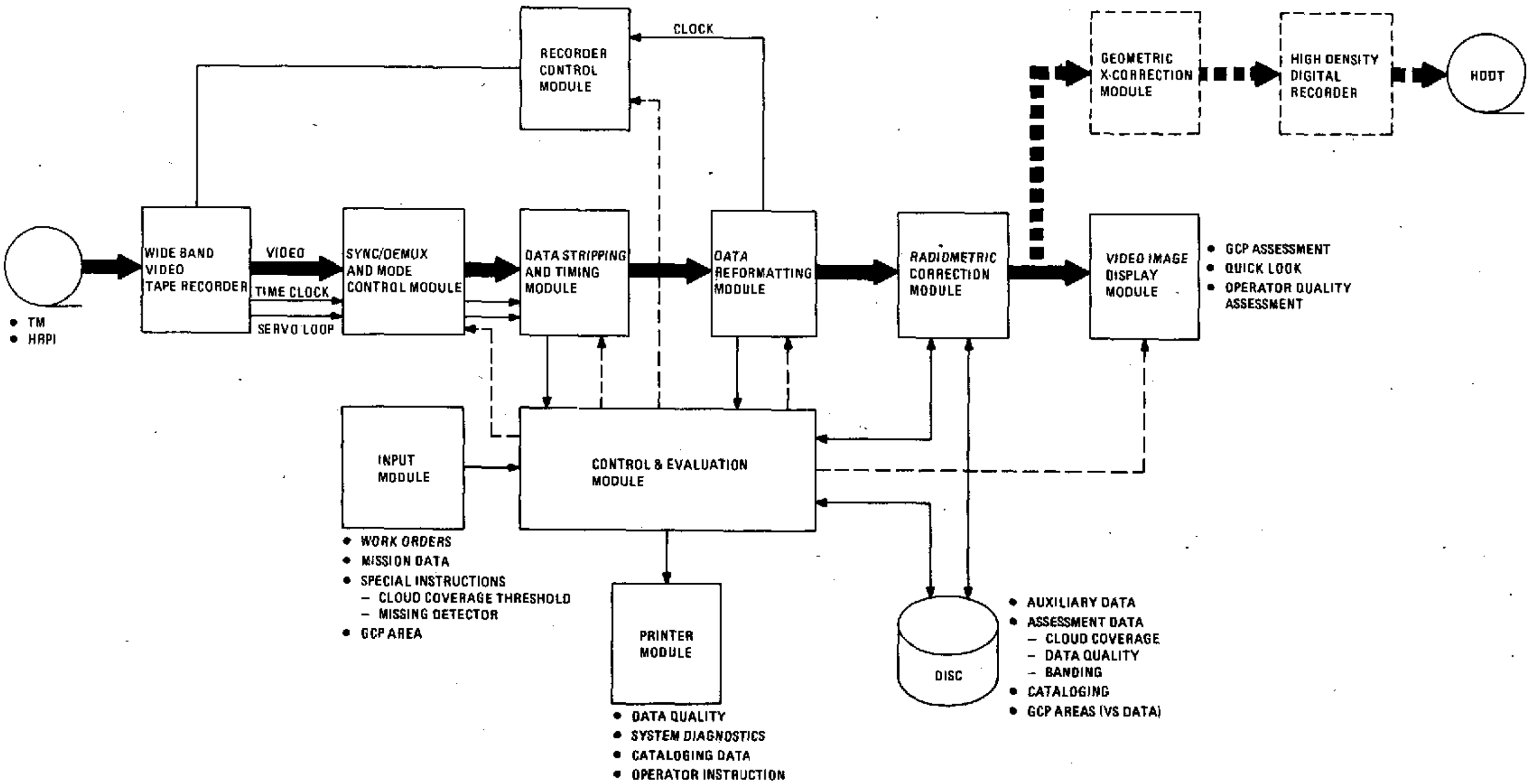


Figure 4-11. Pass 1 Preprocessing Functional Flow

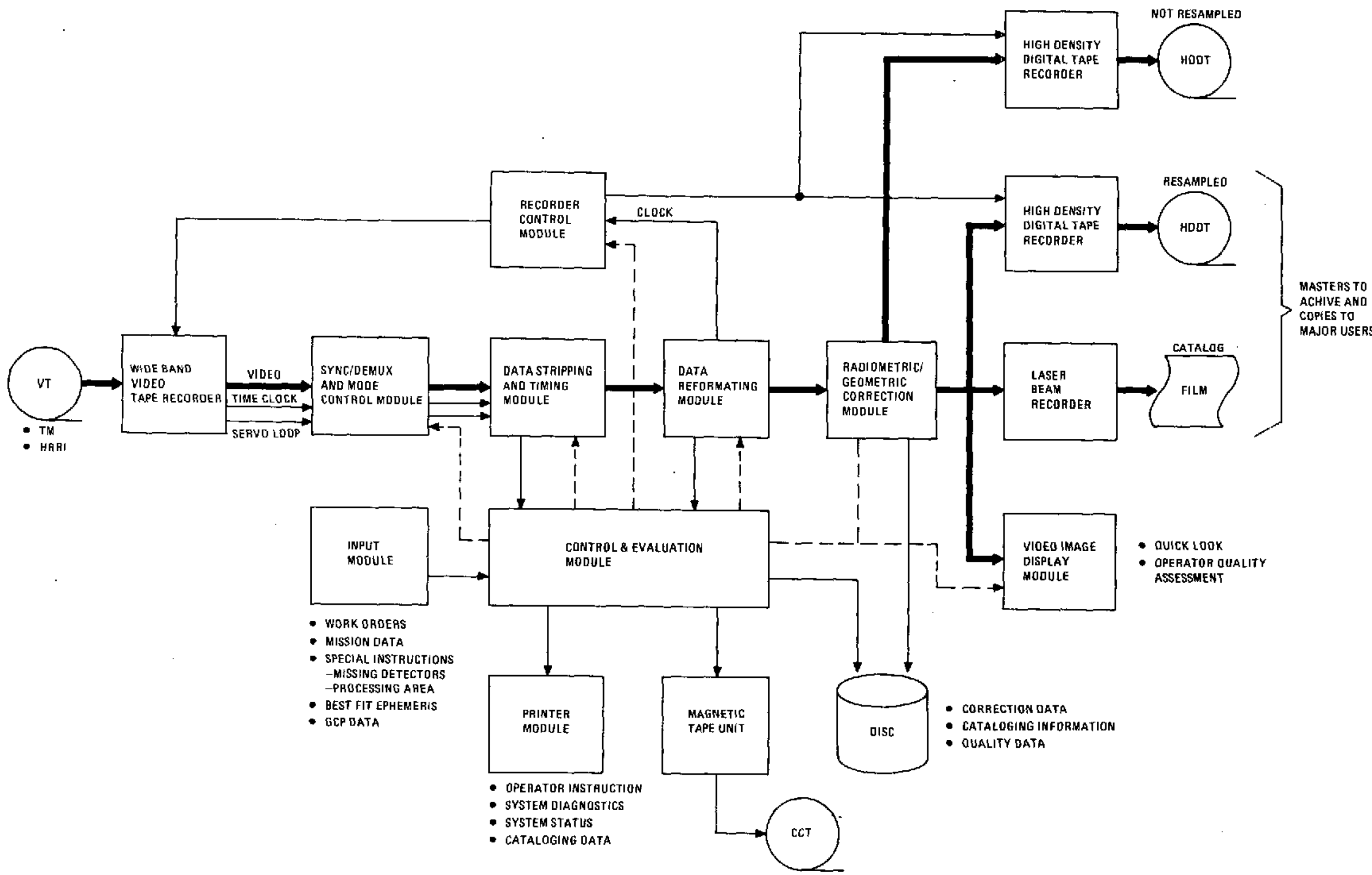


Figure 4-12. Pass 2 Image Correction Functional Flow

is more costly and slower to perform than is the preprocessing, throughput can be maximized by the elimination of unuseable data and tape gaps. The output products from this pass are a corrected HDDT and a film copy of one band (selectable) for cataloging purposes.

Since the standard HDDT output product has been corrected and resampled, the original data should be archived also in the event custom processing is desired (e. g., nearest neighbor instead of sin x/x). An option is to produce a second HDDT during pass 2 which is corrected but not-resampled and has all the processing correction information in it. This can be archived in place of the original video tapes. This latter approach, limited for U. S. data only, is considered the baseline since it reduces the number of tapes to be archived and permits the resampling to be done as an off-line custom processing task.

4.3.3.2 Custom Off-line Processing

Introduction

The custom off-line processing function of the IPE is subdivided into three independent subfunctions which can be executed simultaneously. These are:

- Digital Tape Generation
- Film Image Generation and Processing
- Extractive Processing/Browse

Table 4-17 is a summary of the custom off-line processing functions. Thruput requirements have a major impact on cost of implementation; therefore, major consideration was given to information flow in designing the custom processing subsystems.

Digital Tape Generation

A functional flow depicting the major elements of the baseline Digital Tape Generation Subsystem is shown on Figure 4-13. The CCT generation system is configured primarily for

TABLE 4-17. CUSTOM OFF-LINE PROCESSING FUNCTIONS

Input	Function/Subsystem	Throughput	Output
HDDT	<u>Digital Tape Generation Subsystem</u> ● HDDT Generation - copy only - pixel reformatting - MTF compensation	300 to 1240 scenes/day	HDDT - standard format and packing density
	● CCT Generation - custom projection - copy only - pixel reformatting - digital enlargement - resolution reduction - MTF compensation	15 to 50 scenes/day	CCT - standard format - 1600 and 6250 bits/inch packing density
HDDT	<u>Film Image Generation Subsystem</u> ● Catalog Film Image Generation	40 to 250 scenes/day/ sensor	Film - 1st generation - 9.5" format
	● Custom Film Image Generation	20 to 200 scenes/day/ sensor	
Film (First Genera- ion)	<u>Film Processing Subsystem</u> ● Color Film Generation - false color mix - gamma change	10 to 100 scenes/day	Film and Prints - catalog film strip (film only) - color products (2nd gen. & 3rd) - B/W Products (2nd generation)
	● Photo copying - catalog film strip - B/W and color with prints	2 to 10 copies 50 to 500 scenes/day	
	● 2X and 4X Enlargement - B/W and color - Prints	(included in above number)	
HDDT CCT Film	<u>Extractive Processing Subsystem</u> ● classification ● feature recognition ● feature selection ● training	15 scenes/day	CCT Photo copy Hard copy printout
	<u>Browse Facility</u> ● data viewing ● photo copy	100 scenes/day	Visual Display Film Hard copy printout

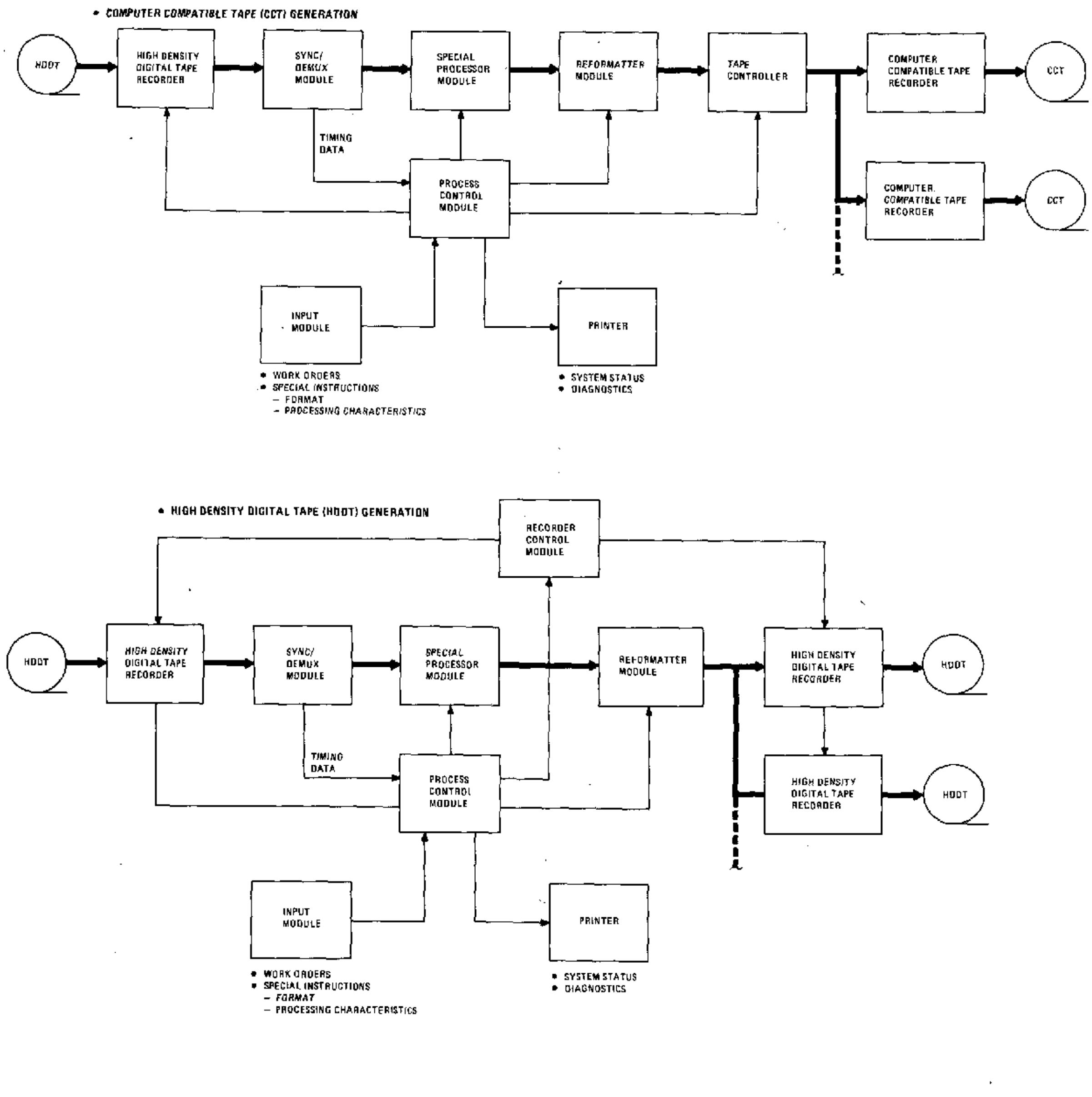


Figure 4-13. Digital Tape Generation Subsystem Functional Flow Diagram

the purpose of generating computer compatible tapes from corrected data on existing HDDT's. The special purpose module is a micro-programmable processor or special digital hardware for performing the custom processing functions (e. g. digital enlargement, MTF compensation) listed in Table 4-17. The reformatter module generates the necessary tape format for the CCT's.

The front end of the HDDT generation system is configured identical to the CCT generation system with the option of utilizing the same CCT special processor to custom process data produced on HDDT (except UTM Map Projection). Since the primary purpose of this system is to produce multiple copies of existing HDDT's, parallel output tape recorders will be utilized to increase tape production and minimize total system cost.

Film Image Generation and Processing Subsystem

The major elements of the Film Image Generation and Processing Subsystem are shown in Figure 4-14. The approach, based on the design/cost trade offs presented in Section 4. 3. 4. 2. 2, utilizes an intermediate HDDT preprocessing system to generate an efficiently packed HDDT for processing by the film image generation system to maximize the efficiency of the more expensive laser beam image recorders.

Extractive Processing/Browse

The similarities in equipments needed to satisfy the extractive processing and browse requirements led to a combination of these functions into a single subsystem. The functional flow of this subsystem is shown in Figure 4-15. Multiple terminals and bulk storage are used to increase efficiency of input/output devices and special processors.

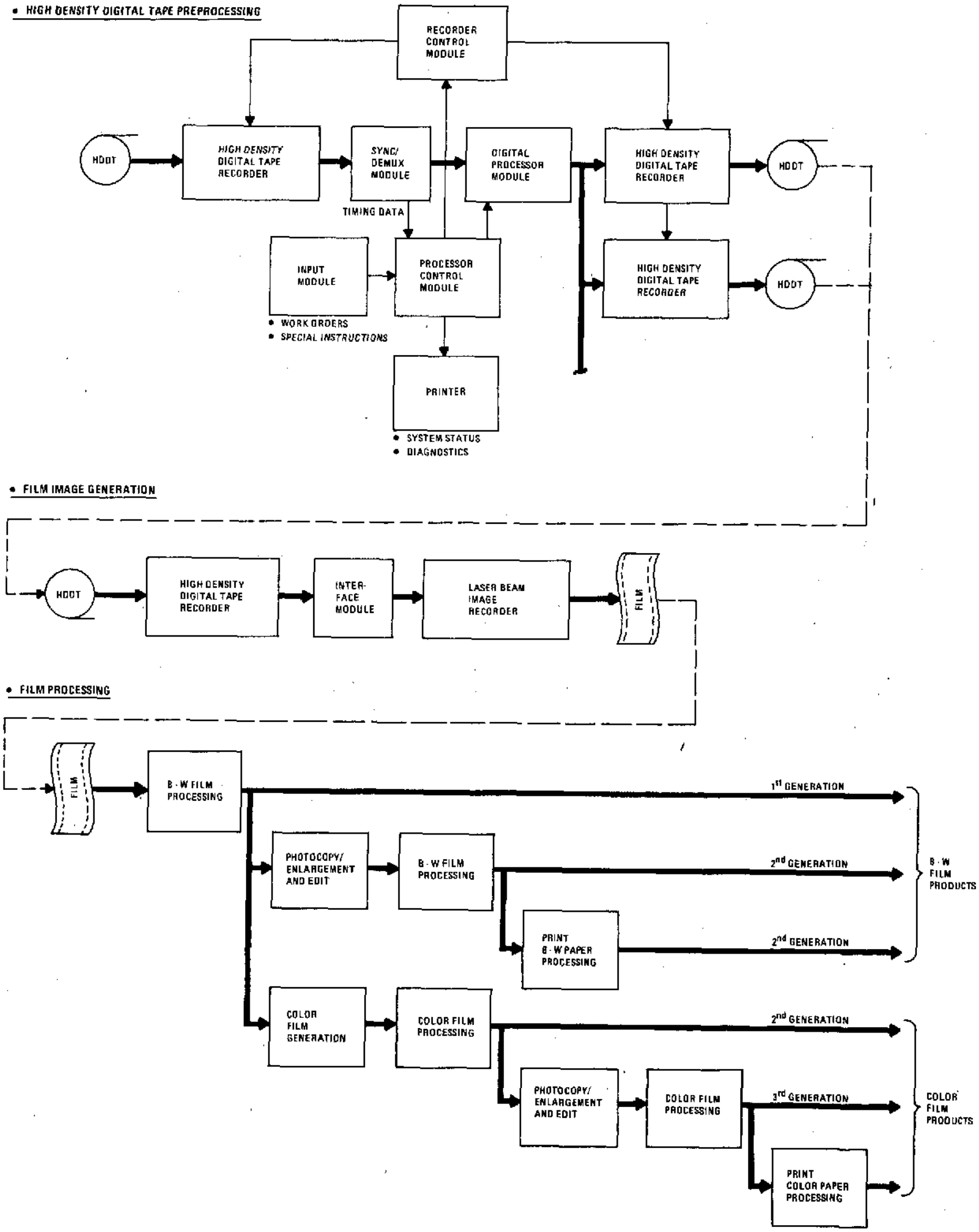


Figure 4-14. Film Image Generation and Processing Subsystem, Functional Flow Diagram

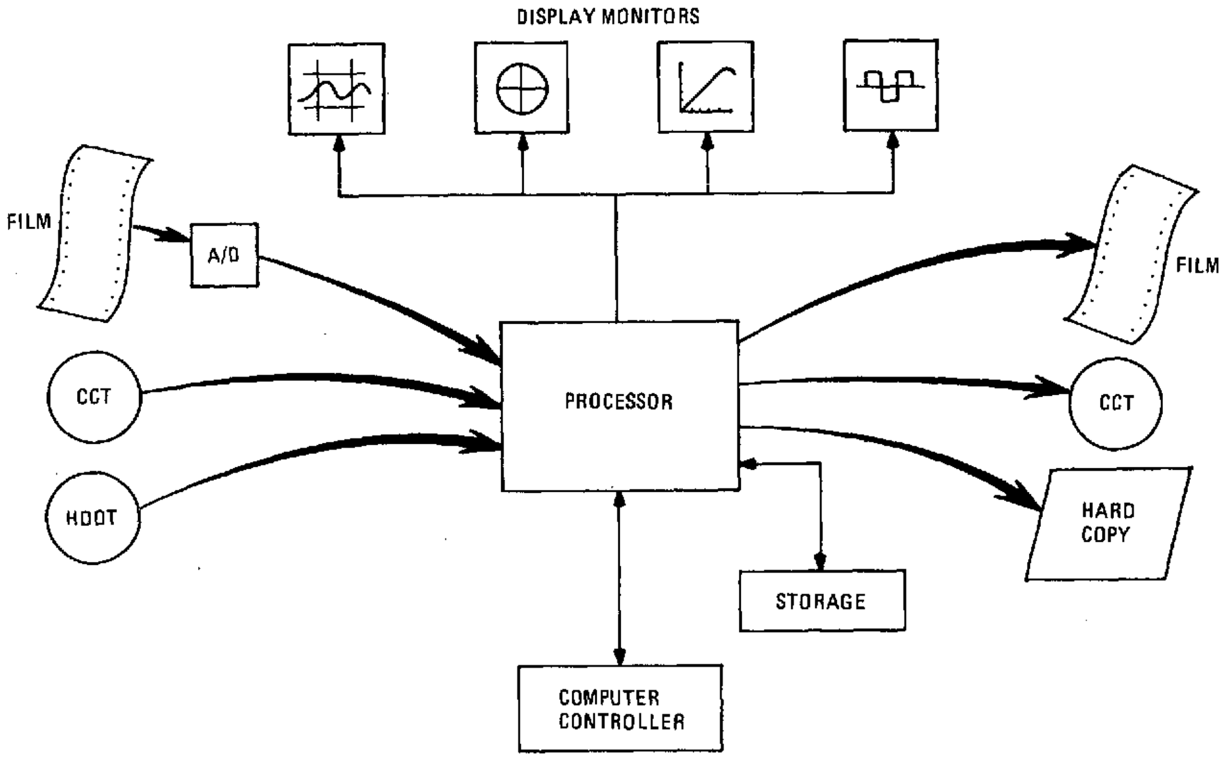


Figure 4-15. Extractive Processing/Browse File Functional Flow Diagram

4.3.4.1 Standard On-Line Processing

4.3.4.1.1 Digital Image Correction Design/Cost Tradeoffs

Introduction

A number of implementation approaches for performing the standard on-line processing functions exist which are applicable to the EOS mission. Image processing hardware technology is sufficiently advanced for general purpose computers, special purpose processors and micro-programmable processors such thay they can be used independently or in various combinations to meet the very large processing loads required.

The purpose of this section is to discuss three candidate implementation schemes for performing the standard on-line correction of EOS data, compare the total costs of these systems, and make recommendations concerning their suitability for performing image correction. Figure 4-16 depicts the difference between the three implementation configurations considered in this study.

Requirements Summary

A summary of the performance requirements which formed the basis of the standard on-line subsystem cost tradeoffs is given in Table 4-18. The various system configurations under consideration were configured and costed for the reference baseline requirement and cost deltas determined for the alternate requirements. These alternate parameter requirements are discussed below:

- Throughput. All reference baseline system configurations were designed to meet a throughput of 40 scenes/day and were then extended without changing the fundamental design concept (otherwise it was considered an alternate) to identify performance/cost breakpoints at significant throughputs. Bench marks for cost and performance were specified at throughputs of 100, 175 and 250 (or the highest obtained) scenes/day.

- Instrument Type. The Hughes oscillating mirror Thematic Mapper instrument and the Westinghouse staggered array were selected as the reference baseline for performing system designs, developing cost deltas, and determining impacts for the various other instrument approaches specified.

- Data Format. The baseline format selected was that produced by the various instruments (both TM and HRPI) and a baseline on-board multiplexing scheme. The alternate approach was to perform all reformatting functions prior to receipt of data at the IPE (e. g., on board the spacecraft).

- Resampling. The various candidate resampling techniques produce a very wide range of computational loading for the image correction system and therefore affect its cost/performance significantly. The specified baseline technique was the cubic approximation to the $\frac{\sin x}{x}$ which produces the

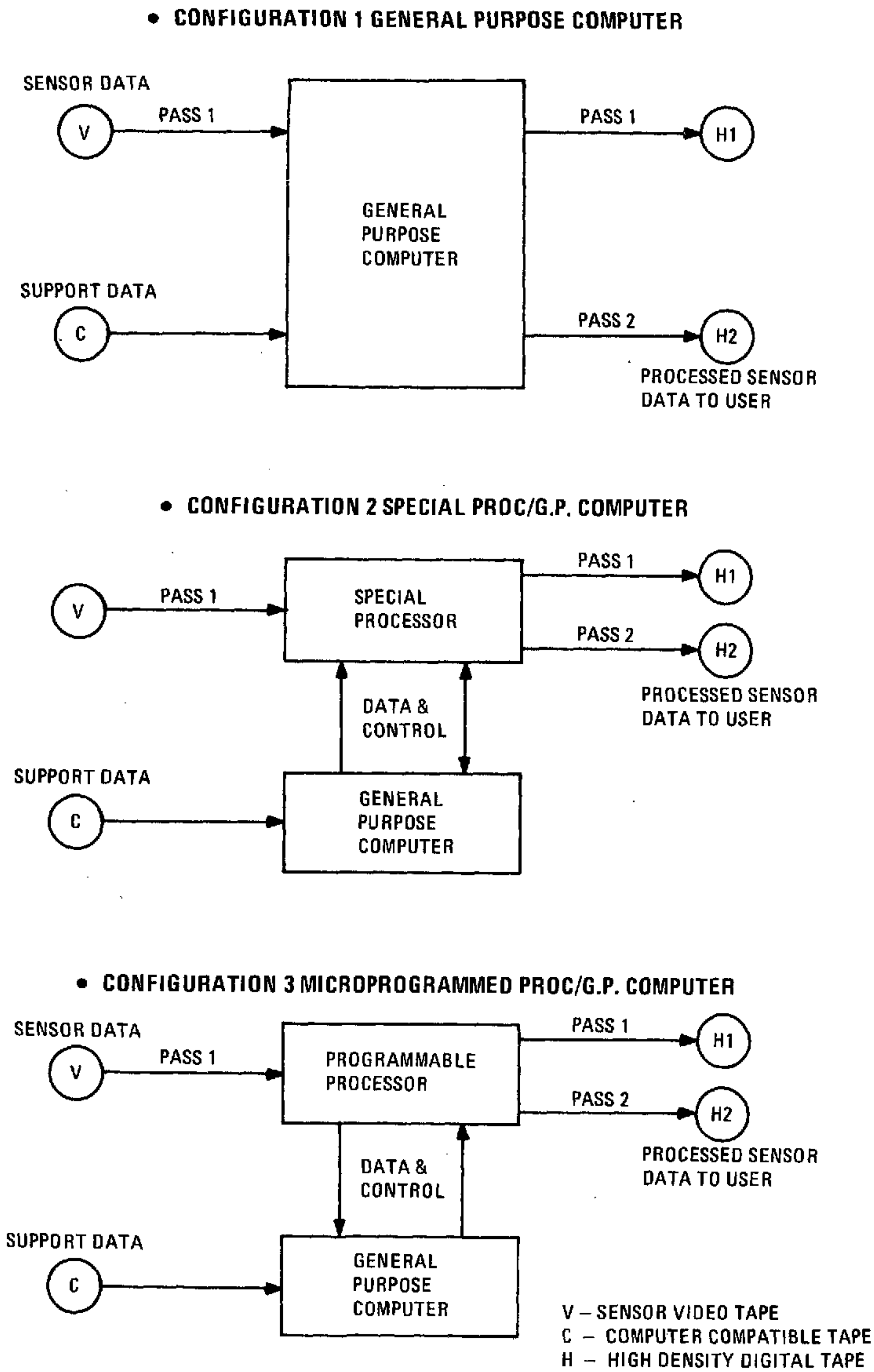


Figure 4-16. Digital Image Correction Subsystem Configuration

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TABLE 4-18. DIGITAL IMAGE CORRECTION SUBSYSTEM REQUIREMENTS SUMMARY

Parameter/ Function	Reference Baseline	Alternatives
Processing Method	Performed Digitally	None
Throughput	40 scenes/day/sensor (1000 sec of data)	100 scenes/day/sensor (2500 sec of data) 175 scenes/day/sensor (4375 sec of data) 250 scenes/day/sensor (6250 sec of data)
Processing Time Available	40,000 sec/day	None
Instruments: TM	Hughes	Honeywell Te-Gulton
Instruments: HRPI	Westinghouse	See Note Below*
Resampling Technique	Sin X/X	Nearest Neighbor Bilinear Interpolation
Computational Accuracy	3m (1σ)	None
Input Format: TM	• Serial Data Stream • Spectrally Inter-leaved • Integral Pixel Offsets between spectral bands	All required formatting performed prior to input of data to IC/DPG subsystem. This includes reversing of alternate TM sweeps and assembling of complete HRPI lines.
HRPI	• Serial data stream • Spectrally inter-leaved • Band-to-band regis-tered • Staggered array	
Oversampling: TM	40%	0-60%
HRPI	0%	None
Input Medium*	HDDT (e.g. output of Ampex FR1928)	Data stream via channel from formatting hardware

Parameter/ Function	Reference Baseline	Alternatives
System Considerations	• 420 n. mi orbit • 185 KM TM Swath • ± 45° HRPI Pointing Angle	None
Sensor IFOV: TM	35×10^{-6} RAD (Band 1-6) 140×10^{-6} RAD (Band 7)	None
HRPI	10×10^{-6} RAD	
Ephemeris Accuracy 1σ	• Predicted 300m in track 300m cross track 200m radial • Best Fit 50m in track 35m cross track 35m radial	None
Attitude Control Accuracy 1σ	• Position Pitch 0.007° Roll 0.007° Yaw 0.004° • Rate (each axis) 10^{-5} deg/sec	0.004° - 0.01° 0.004° - 0.01° 0.003° - 0.007° 10^{-4} - 10^{-6} deg/sec
Attitude Measurement Accuracy 1σ	• Position 0.0003° (over 30 sec) 0.0006° (over 20 min) • Rate 10^{-6} deg/sec	None
Geometric Output Accuracy 1σ	±15m using 2D correction, best fit ephemeris, and GCP's	+170m (up to 100 scenes/day in addition to baseline) using 1D correction, best fit ephemeris, no GCP's ±450m (up to 210 scenes/day in addition to baseline, less ± 170m scenes) using 1D corr., predicted ephemeris, no GCP's

Parameter/ Function	Reference Baseline	Alternatives
Map Projection	• U.S. data SOM	UTM
	• Non-U.S. data Best fit cylinder	None
Radiometric Ouput Accuracy	• Differences between detectors - linear variation from 0.5 counts at 0% full scale to 2 counts at 100% full scale • Temporal stability - 0.5 counts from 0-30% full scale, linear variation from 0.5 counts at 30% full scale to 2 counts at 100% full scale	None
Radiometric Correction Character-istics	• Sun calibration req'd. • Internal Cal lamps used • Gain and offset correc-tion is sufficient • One correction table for each TM detector • 256 unique HRPI correction tables • Linear HRPI response	None
Output Products • Standard	HDDT of all processed data	None
Other Processing Functions	• MTF compensation (10% of data) • Failed sensor compen-sation • Cloud cover assessment • Cataloging • Banding Determination • GCP library maintenance • Work order generation	None

*Westinghouse Staggered Array is reference base line, alternatives include Westinghouse Linear Array, Hughes, Honeywell, and TeGulton HRPI Instruments most stringent processing requirement. The performance and cost impact of the bilinear and nearest neighbor technique were also determined.

- Oversampling. The impact of the increased data rate due to oversampling in the Thematic Mapper instrument was investigated.

- Output Projection. The selected output projection system impacts the processing system cost by the increased storage required. The baseline projection, the Space Oblique Mecator projection, was selected because it minimizes the storage requirements. The cost impact of going to a standard UTM projector was considered an alternate.

All the functions, listed in the requirements section (Section 4. 3. 2), can be reduced to an equivalent number of instructions per pixel. This in turn can be related to total instructions per second per processing day as shown in Figure 4-17. These curves provide the basis for sizing and costing the various configurations. It should be emphasized that computer hardware can not be precisely described by a MIPS rate; however, some "ball park" relationships can be assumed.

Alternate Configuration Descriptions

General

Four different system configurations were designed, evaluated and costed for the three generic configurations introduced in this section. The study of the general purpose computer approach was performed by IBM utilizing existing computer technology (hardware and software) and cost data. The micro-programmable processor approach was studied by both IBM and CDC, again utilizing existing processor technology and hardware to evaluate and cost the various configurations. The special purpose processor approach was studied by GE applying system design and hardware technology presently being utilized in existing systems.

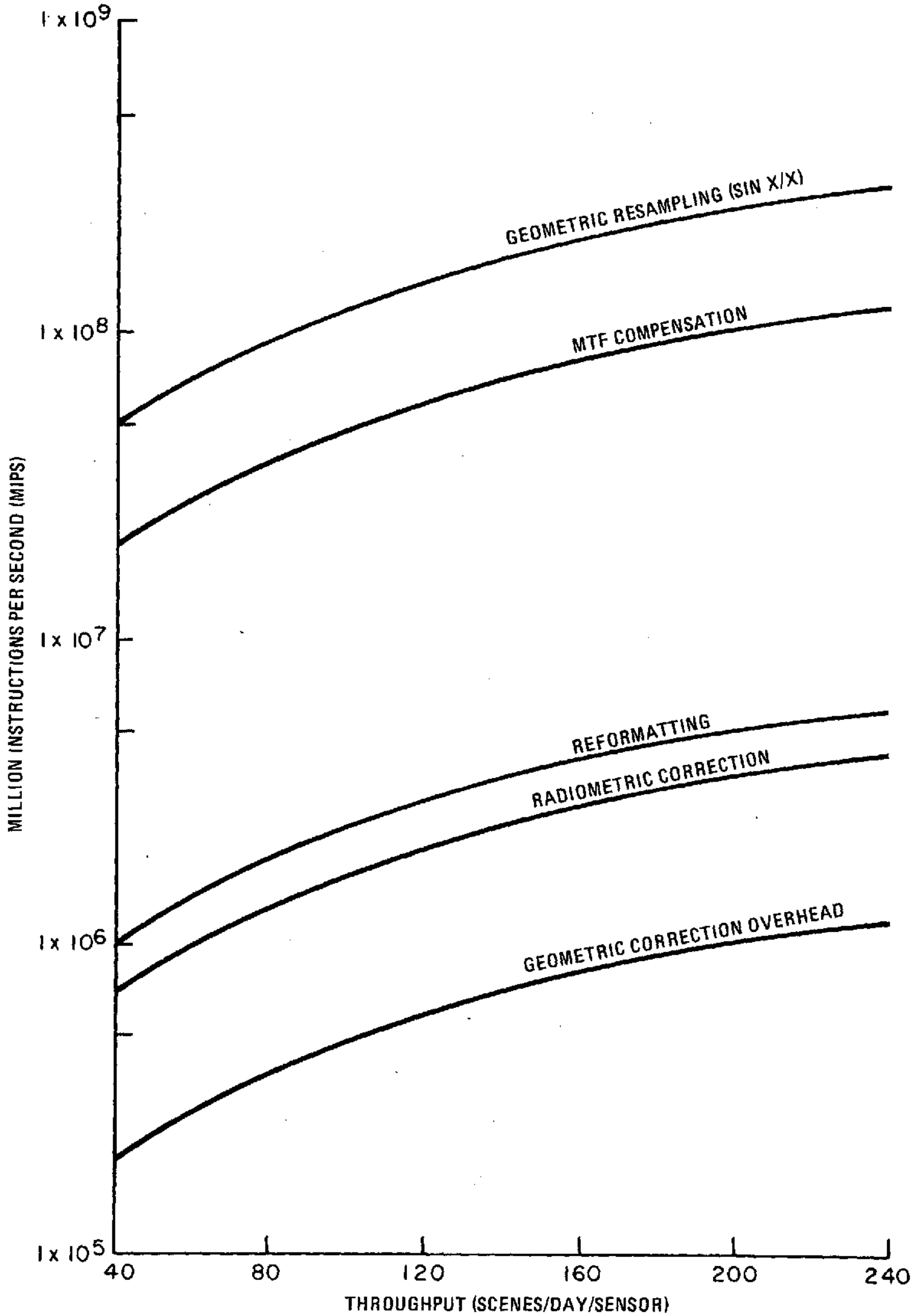


Figure 4-17. Systems Computational Load Vs. Throughput

Hardware block diagrams were prepared for each configuration and used to develop hardware element costs. A software system organization was developed for each configuration and costed. The software implementation costs include coding, debug, test and module integration as well as algorithm and software flow diagram development.

The IBM General Purpose Computer Approach

The hardware module building blocks for the general purpose computer configuration approach is shown in Figure 4-18. This module includes a 370/195 (the most powerful general purpose computer currently made by IBM), high speed 2860 selection channels, two HDDT drives and interfaces, a 3333 disk, two 6250 Bpi tape drives, and a gray scale image display with keyboard.

The software consists of an operating system, major application modules, and input/output support functions as shown in Figure 4-19. The operating system was assumed to be a modification of an existing package such as IBM OS/370. The applications support functions, or the processing algorithms, are categorized into four major applications modules which are: (1) Reformat, (2) Radiometric Correction, (3) Geometric Correction, and (4) Information Management. The input/output support functions control the operations of the various peripheral devices.

To size the hardware and software necessary, instruction count estimates were made, relying heavily on established data loads. In performing this analysis, "equivalent adds" were estimated and considered the reference instruction for the counts used. A multiply operation was considered to be two equivalent adds. Total instruction counts for the day can be divided by 4×10^4 seconds (the available processing time) to arrive at the rate at which instructions must be executed.

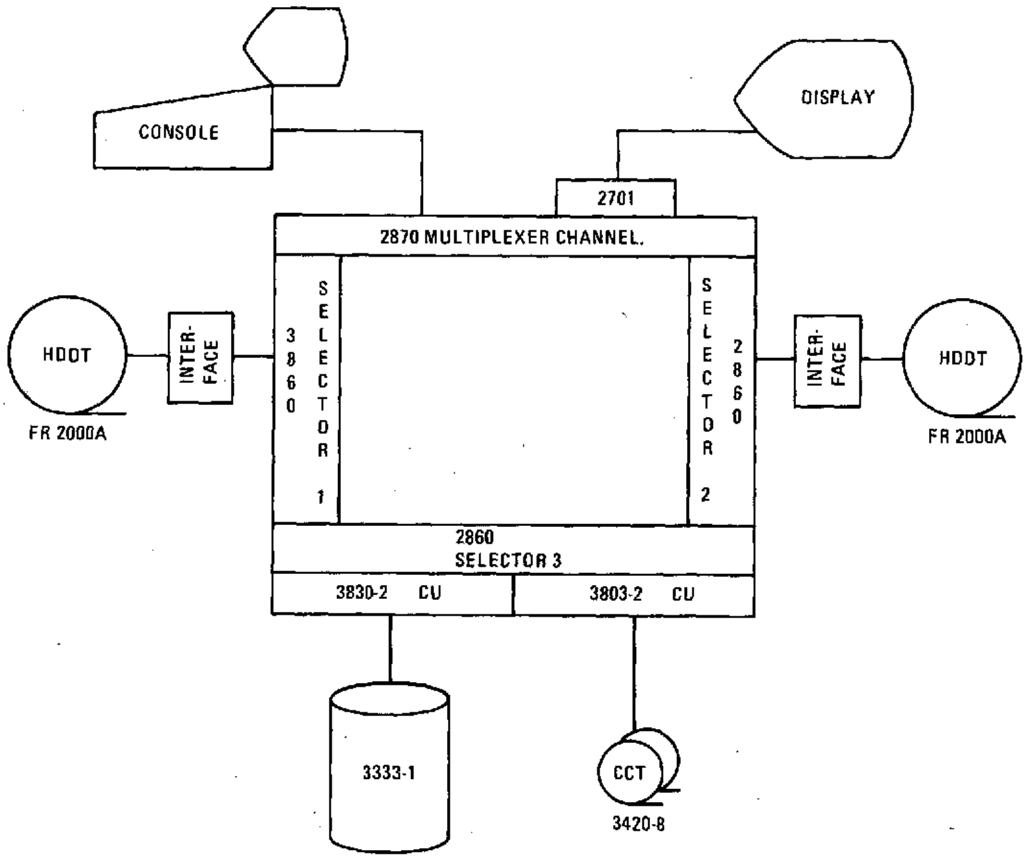


Figure 4-18. General Purpose Computer Hardware Configuration

The baseline hardware module was utilized to cost the general purpose approach over the throughput range from 40 to 250 scenes/day using the $\frac{\sin x}{x}$ resampling technique for 155% of the data. The computational load is significantly reduced if nearest neighbor resampling is utilized for 100% of the data. Therefore, an alternate hardware module configuration, shown in Figure 4-20, was selected utilizing an IBM 370/168 computer, high speed 2880 block multiplexer channels, a 3333 disc, two 6250 Bpi tape drives and a gray scale image display with keyboard. The software organization for the alternate configuration is identical to that previously discussed for the baseline module.

The CDC Flexible Processor Approach

The hardware configuration for the flexible processor approach is shown in Figure 4-21. The support Processing Subsystem utilizes a CYBER 172 computer which is

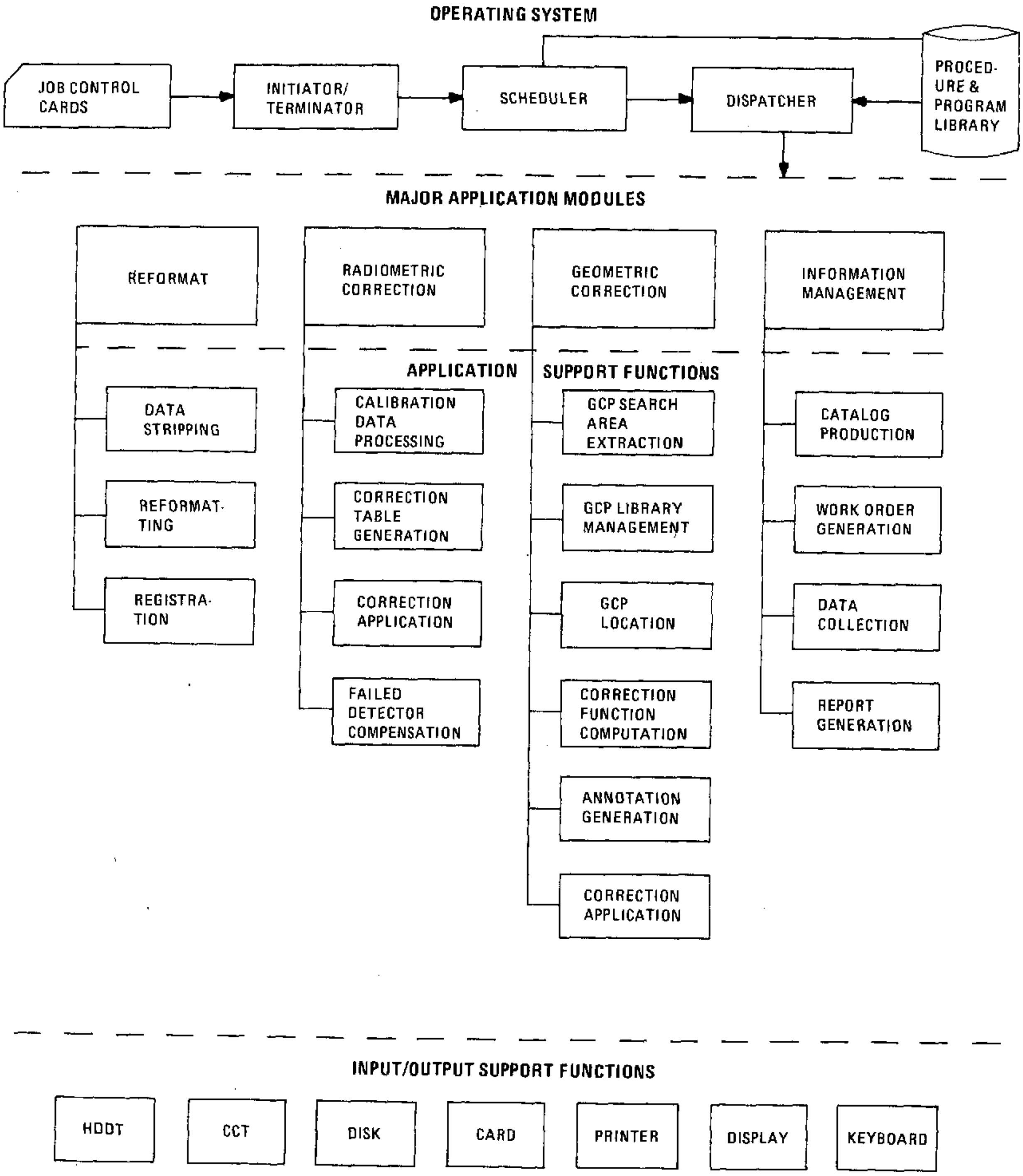


Figure 4-19. Software Organization

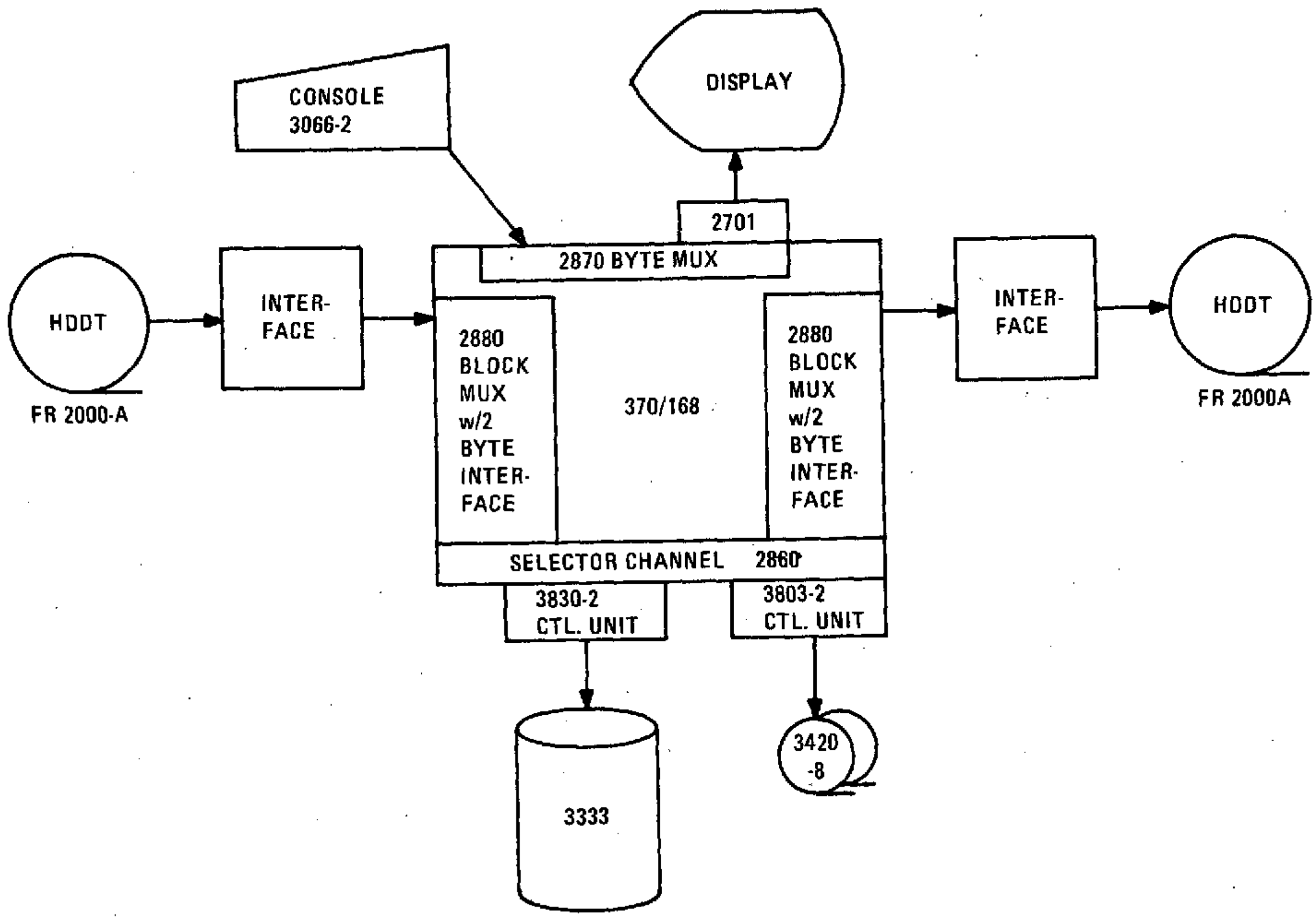


Figure 4-20. Alternate General Purpose Hardware Configuration

a small general purpose computer of 1 million instructions per second throughput rate. The remaining subsystems (except Mass Storage) utilizes the CDC Flexible Processor (FP) - a micro-programmable digital image processor.

The FP is designed for high speed I/O and multicomputer (array) configurations. The FP has a 125 ns instruction cycle with a 48 bit 3 address micro instruction. Use is made throughout the system of high speed (300 ns) metal oxide semiconductor (MOS) random access memory. The MOS memories are directly addressed by the FPs using direct storage access (DSA) channels. FP to FP data transfers and control are accomplished by FP and AQ channels in the Flexible Processor.

The primary data path in this system design flows from the Input Processing Subsystem through the MTF Subsystem and to the Resampling Subsystem before being output to HDDT (high density digital tape). All computations performed on a per pixel basis are computed external to the Support Subsystem.

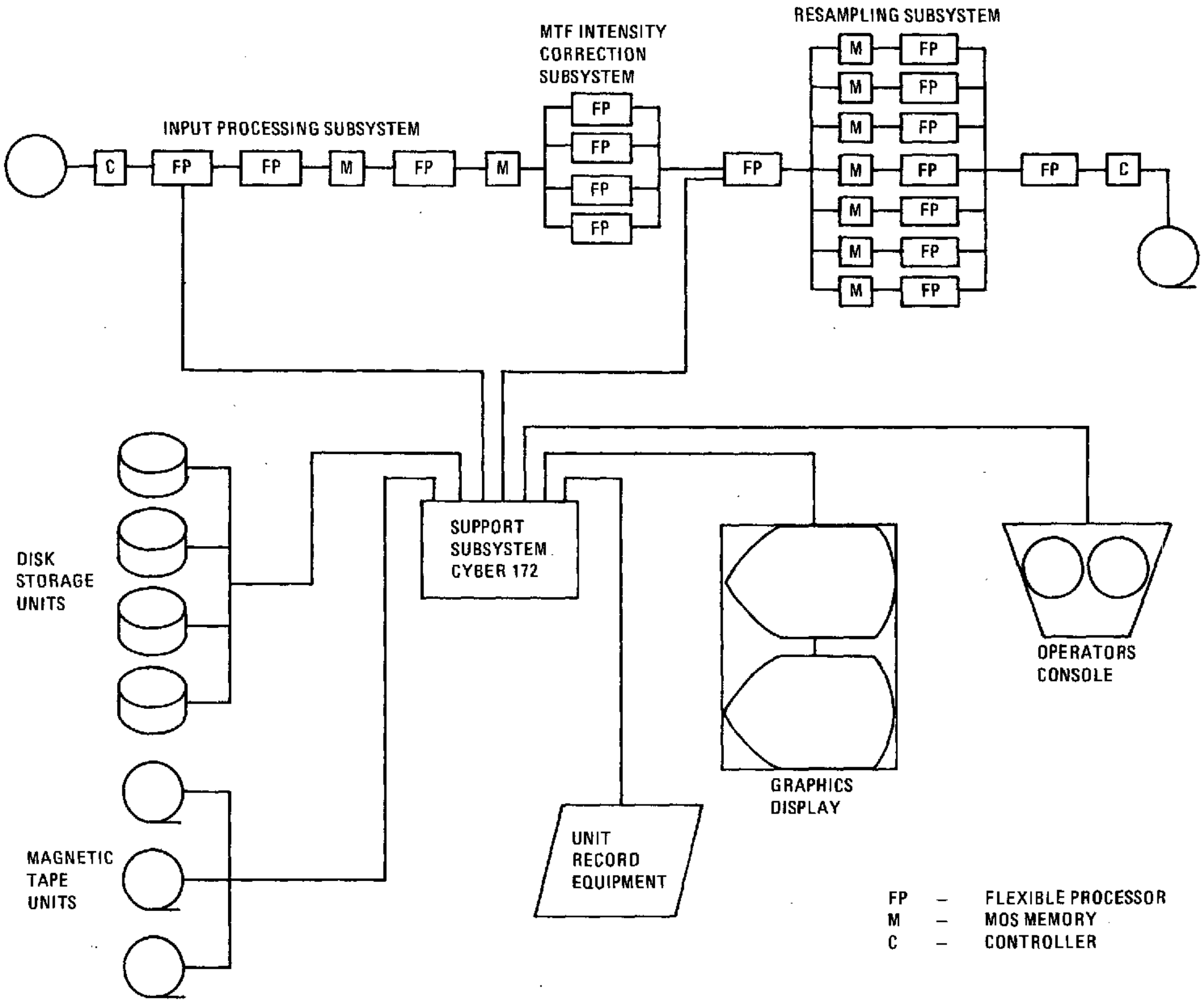


Figure 4-21. Flexible Processor Hardware Configuration

The Mass Storage Subsystem is composed of four 844 disk drives with a dual access controller. The dual access allows simultaneous access by both the Input Subsystem and the Support Subsystem. The primary use of the disk is for storage of subscenes of data for correlation with points in the Ground Control Point Library (also stored on disk). Requests from operators at the display will then result in the Support Processor transferring the data from disk to display. The disk may also be used for buffering of scenes from the Input Processor, allowing the Support Processor computation time to generate inverse transformation functions.

The display consists of a 777 CYBERGRAPHICS interactive graphics system with dual CRT screens. Full interactive capability exists with light pen and keyboard entries. The 777 display features a mini-computer controller allowing programmable subroutines for offline support of graphic functions. An example might be magnification of subscene areas. The display is used for GCP correlation by selection of suitable subscene areas and lightpen indication of startup areas for the digital correlation algorithm.

The software module organization showing assignment of software to subsystem and hardware type is given in Table 4-19. The software is organized according to subsystem assignment and type of hardware in which it is resident.

<u>The IBM Micro-Programmable Processor Approach.</u>

The baseline hardware configuration for the micro-programmable processor approach is shown in Figure 4-22. It consists of three basic units:

- PreProcessing Unit (PPU)
- Special Purpose Micro-programmable Processor (SPP)
- General Purpose Processor (GPP)

In the PPU, special circuitry will establish sync with the HDDT and presents 28 bytes at the output of the decomutation unit at each byte transfer period. The significant

TABLE 4-19. SOFTWARE MODULE ORGANIZATION

Function	Subsystem	Hardware Type
1. RDAR-Read data and Reformat	Input Processing	Flexible Processor
2. RADCAL-Radiometric Calibration	Input Processing	Flexible Processor
3. MTF-Modulation Transfer Function	MTF Intensity Correction	Flexible Processor
4. BAND1-Banding Summation	MTF Intensity Correction	Flexible Processor
5. MDET-Missing Detector Correction	MTF Intensity Correction	Flexible Processor
6. LILC-Line Length Correct	MTF Intensity Correction	Flexible Processor
7. GCP-Ground Control Point Correlation	Support Processing	CYBER 170
8. DIS-Display Processing	Support Processor	CYBER 170
9. BAND2-Banding Histogram analysis	Support Processor	CYBER 170
10. RCUP-Radiometric Calibration Table Update	Support Processor	CYBER 170
11. GPLUP-Ground Control Point Library Update	Support Processor	CYBER 170
12. EPHEM-Emphemris Data Processing	Support Processor	CYBER 170
13. SERR-Systematic Error Compensation	Support Processing	CYBER 170
14. ATIC-Attitude Control Data Processing	Support Processing	CYBER 170
15. GRID-Grid Point location	Support Processing	CYBER 170
16. GTFUND-Transformation Function Determination	Support Processing	CYBER 170
17. ITEV-Inverse Transform Evaluation	Support Processing	CYBER 170
18. GAIT-Generate Archive Information Tape	Support Processing	CYBER 170
19. DCOOR-Data Coordination	Resampling	Flexible Processor
20. RSAM1-Resampling by Cubic Convolution	Resampling	Flexible Processor
21. RSAM2-Resampling by Bilinear Interpotation	Resampling	Flexible Processor
22. RSAM3-Resampling by Nearest Neighbor	Resampling	Flexible Processor
23. FOUT-Format data for output	Resampling	Flexible Processor
24. CHDDT-Control High Density Digital Tape Drive	Resampling and Input Processing	Flexible Processor

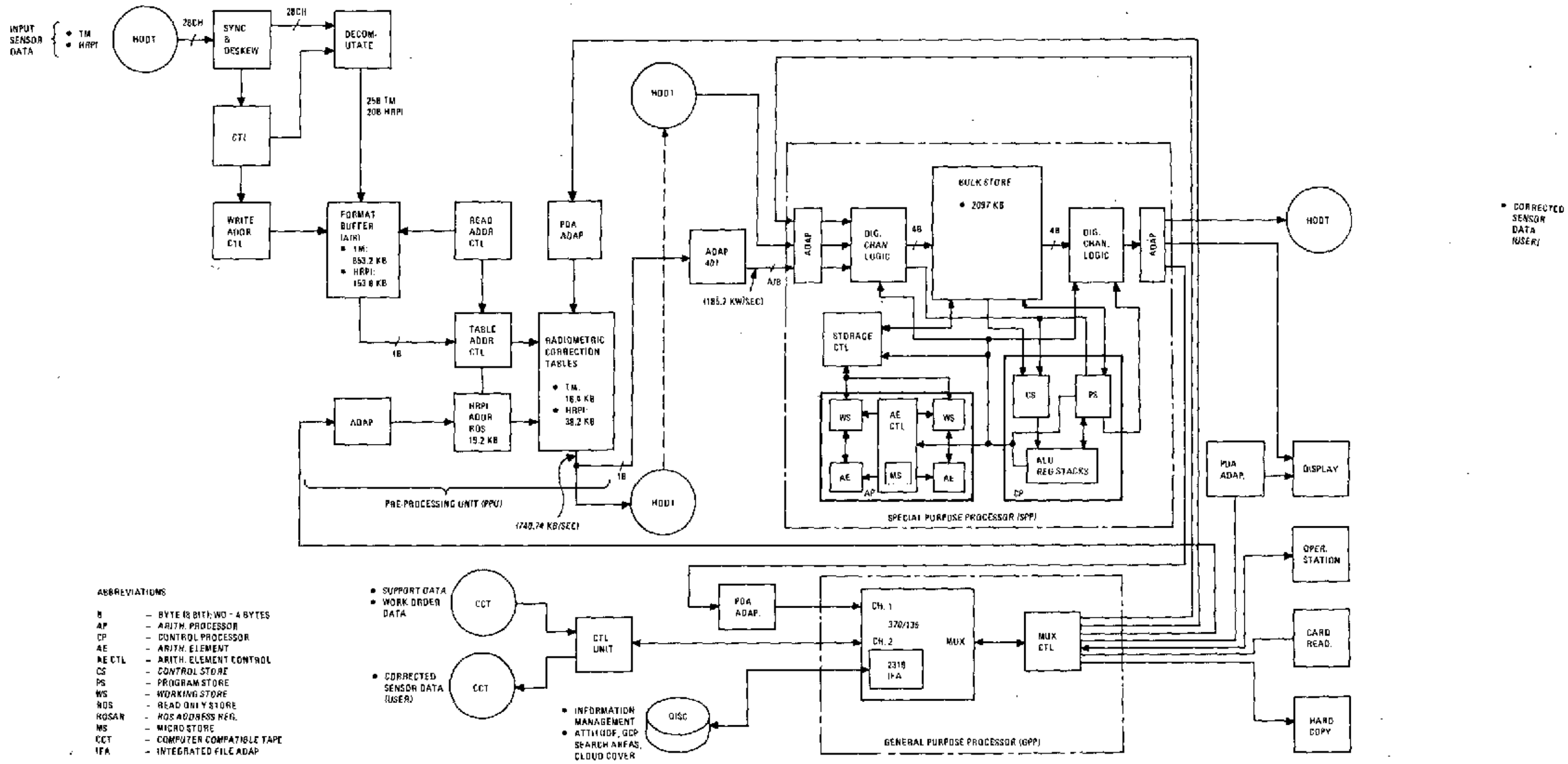


Figure 4-22. Digital Image Correction Subsystem Block Diagram

bytes active at each byte period are inserted into the Format Buffer - which is of the A/B type (i.e., while the data from one sweep is being read into one half of the buffer, data from the previous sweep is being read out of the other half). The write/read addressing circuitry is hardwired to format either TM or HRPI data streams so that read-out order is spectrally interleaved, line sequential.

Data readout from the Format Buffer is then used, in part, as an address to fetch a corrected data value from the Radiometric Correction Tables. In order to select the appropriate table for any give sensor, its time location (0-4799) and band number are used as the address for a Read Only Store (ROS) which produces the proper table address and is concatenated with the data byte value to form the Correction Table address. This ROS must be personalized at IMPL time since it is power-down volatile.

The SPP consists of a microprogrammable unit termed the Control Processor (CP) which serves a supervisory and I/O control function in the system. Another microprogrammable unit contained in the SPP is the Arithmetic Processor (AP). The AP has been designed to perform arithmetic operations (particularly adds and multiplies) at high speed. It is in this unit that all computational algorithms are performed. The basic data link between these units and the input/output parts is the Bulk Storage (BS) unit. As seen in Figure 4-22, the BS unit communicates with all units of the AU. To facilitate execution efficiency, both the AP and CP have self-contained high-speed storage units - these can be considered cache-like devices. The system is modular in terms of AE, WS subunits within the AP - 1 to 4 AE, WS subunits may be specified for a single AU to more closely match the system capabilities to the processing requirements. The CP microinstruction execution time may vary from 300 nsec to 600 nsec depending on instruction type. The AP microinstruction execution time is 100 nsec - which indicates only execution initiation periodicity, not latency, since the AE part of the AP is pipe-line structured.

The GPP is an IBM 370/135 with 245K bytes of memory. It is connected to the SPP and to CCT drives by standard high-speed channels and to a 2319 disk unit through a

2319 Integrated File Adapter. Connection with the PPU, display, keyboard, card reader, and printer is through a standard multiplexer channel.

The GE Special Purpose Processor/General Purpose Computer Approach.

The hardware configuration for the special purpose computer approach is shown in Figure 4-23. It consists of the following elements:

- General purpose computer and standard peripherals
- Special purpose processor
- Input data preprocess equipment, and
- Standard equipment

The general purpose computer is a PDP 1145 with 64K words of memory. It utilizes the RSX-11D multi-task operating system. All ground control location calculations are performed in the computer but by the use of spacecraft rate data all but one of these ground control correlations are over a very small search area (i.e., about 3 x 3 pixels). The computer controls and sets up all the special hardware and performs all the radiometric and geometric correction function calculations. The software programs are shown in Table 4-20.

The special purpose processor consists of a radiometric correction module, a geometric correction and data reformatting module and an operation correction module. The radiometric correction module uses a 16 breakpoint table look-up function generator to perform sensor correction. The function generator is loaded with the proper coefficients from a solid state shift register buffer. The buffer can hold up to 19,200 sets of correction tables which is one table per detector for HRPI. The geometric correction and data reformatting module consists of a X-corrector, a solid state buffer memory and a X-corrector. The X-corrector performs both the data reformatting and the along the scan line resampling. The solid state buffer memory buffers

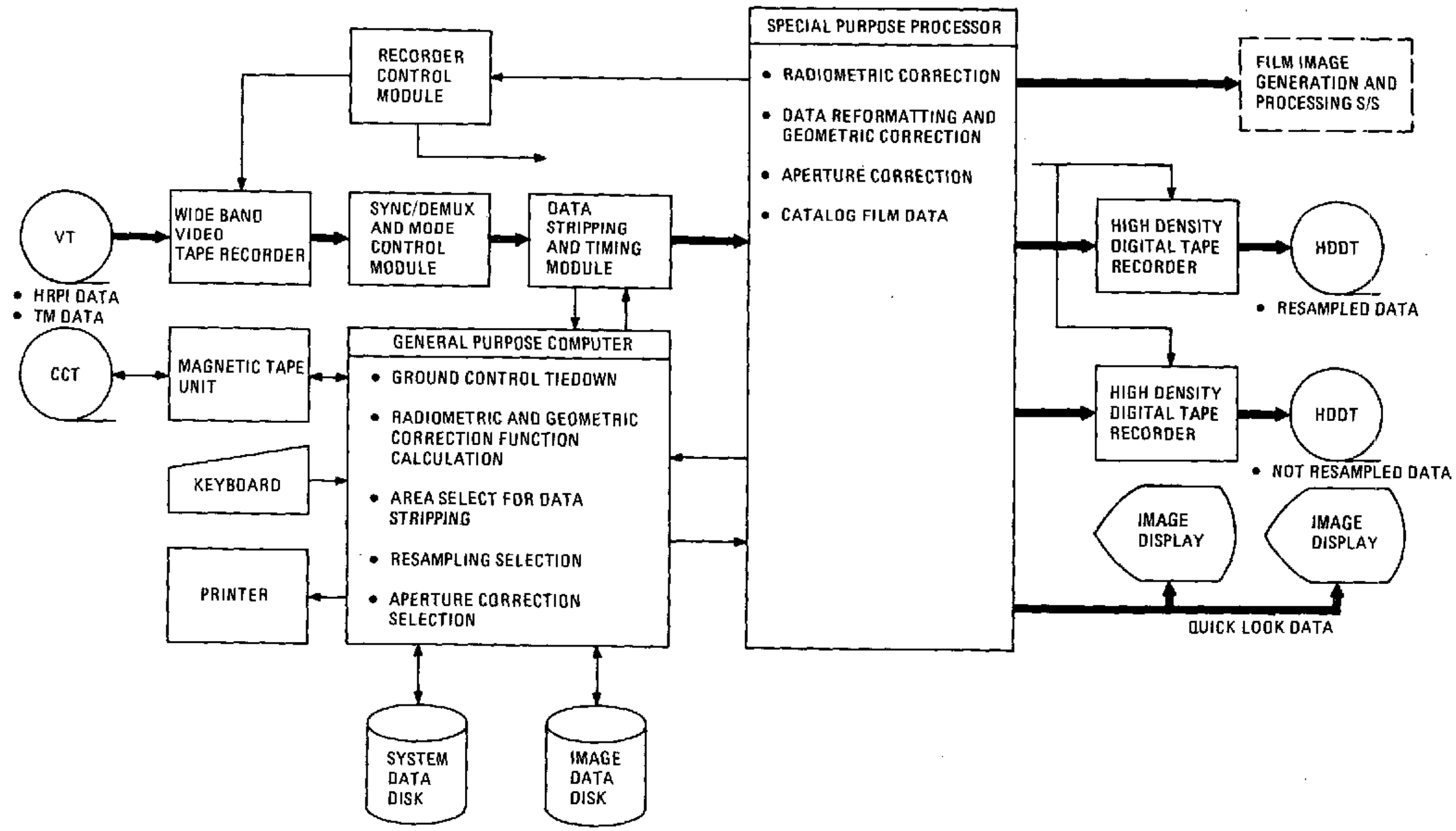


Figure 4-23. GE-EOS On-Line Special Purpose Processor/General Purpose Computer System Program

TABLE 4-20. SOFTWARE PROGRAMS

Classification	Program Listing
Standard Software	• RSX-11D Operating System • PDP Diagnostic Software • Subroutine Library Software • Others
Special Purpose Processor Control & Intialization Software	• Special Hardware Control Software • Special Hardware Intialization Software • Data Stripping and Storage Software
Application Software	• Radiometric Correction Function Calculation Software • Geometric Correction Function Calculation Software • Ground Control Point Location Software

200 lines of data required for the Hughes Thematic Mapper instrument. The Y-corrector operates on the data in the buffer to provide two dimensional correction for the scenes where mapping in Space Oblique Mecator projection is required. The aperture correction module consists of a 5-line solid state memory buffer and a 5 x 5 programmable hardware correlation filter. The special purpose processor for the baseline configuration operates at 25 Mb/s and processes up to 7 channels in parallel.

The input data processor consists of a syn/demux and mode control module, a data stripping and timing module and a recorder control module. The sync/demux module is a modification of existing hardware. The data stripping and timing module consists of the programmable line and element counters, a solid state data buffer, a computer interface and a system clock. This module selects predefined ground control areas and sensor calibration data from the data stream, buffers the data and transfers the data to the PDP 1145 general purpose computer for storage on the Image Data Disk. The recorder control module consists of two monitors which track the special purpose hardware input and output buffer registers, a difference circuit and two driver amplifiers. This module adjusts the tape speed of the input and output controllers to compensate for the different input and output data rates caused by the along the scan line pixel distortion.

The standard equipment consists of a 120 Mb/s Wideband Video Tape Recorder, two 40 Mb/s High Density Digital Tape Recorders and two black and white 1000 line image display monitors which can operate in a frame or moving window mode.

The basic configuration can satisfy a throughput up to 70 scenes/day/sensor. For higher throughput rates, the configuration is similar except that more paralleling of hardware components are required to handle the increased data rates. For throughput rate from 70 to 105 scenes/day/sensor, the configuration is modified to include additional hardware multipliers and adders to handle the 40 Mb/s data rates. For throughput rates from 105 to 180 scenes/day/sensor the configuration is modified by additional hardware processing elements and a change from 40 Mb/s high density digital tape output recorders to 120 Mb/s wideband video tape output recorders to handle the increased data rates. For throughput rates from 180 to 250 scenes/day/sensor, the configuration requires an additional processing element in the special purpose processor to process the data at approximately real time rate (100 to 120 Mb/s).

Design/Cost Tradeoffs.

Tables 4-21 thru 4-23 summarize the results of the cost/performance tradeoffs performed for the standard on-line processing functions (both pre-processing and image correction). Comparison of the system costs (including design, development and implementation costs) in Table 4-21 for the four configurations eliminates the general purpose approach as a contender for any ground processing configuration where a significant amount of $\frac{\sin x}{x}$ resampling is employed. Even the alternate general purpose computer configuration designed specifically for all nearest neighbor is significantly higher

TABLE 4-21. DIGITAL IMAGE CORRECTION SYSTEM COSTS FOR BASELINE EXTENDED AND ALTERNATE DESIGNS

Candidate Approaches \ Designs		Baseline System Design	Extended Baseline Designs For Increased Throughput			Alternate -Baseline System Design
		• 40 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 100 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 175 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 250 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 40 Scenes/Day/Sensor • Nearest Neighbor Resampling
IBM General Purpose Computer Approach	Configuration Description	• 6 - 370/195 Computers	• 7 - 370/195 Computers	• 8 - 370/195 Computers	• 9 - 370/195 Computers	• 1 - 370/168 Computers
	Cost	$43.6M	$50.8M	$58.1M	$65.3M	$4.48M
	Development Risk	Low	Low	Low	Low	Low
CDC Flexible Processor Approach	Configuration Description	• 1 Cyber 172 • 16 Flexible Processors	• 1 Cyber 172 • 16 Flexible Processors	• 1 Cyber 172 • 29 Flexible Processors	• 1 Cyber 172 • 44 Flexible Processors	• 1 Cyber 172 • 9 Flexible Processors
	Cost	$4.10M	$4.98M	$5.42M	$7.25M	$3.75M
	Development Risk	Low	Low	Moderate	Moderate	Low
IBM Micro-programmable Processor Approach	Configuration Description	• 1 - 370/135 • 1 Micro-programmable processor • 2 Arithmetric Elements	• 1 - 370/135 • 1 Micro-programmable processor • 4 Arithmetric Elements	• 1 - 370/135 • 2 Micro-programmable processors • 2 Arithmetric Elements	• 1 - 370/135 • 2 Micro-programmable processors • 4 Arithmetric Elements	• 1 - 370/135 • 1 Microprogrammable processor • 1 Arithmetric Elements
	Cost	$3.11M	$3.25M	$3.55M	$3.85M	$3.09M
	Development Risk	Low	Low	Low	Low	Low
GE Special Purpose Hardware Approach	Configuration Description	• 1 PDP 1145 • 1 Special Processor	• 1 PDP 1145 • 1 Special Processor	• 1 PDP 1145 • 1 Special Processor	• PDP 1145 • 1 Special Processor	• 1 PDP 1145 • 1 Special Processor
	Cost	$2.15M	$2.38M	$2.91M	$3.07M	$2.10M
	Development Risk	Low	Low	Low	Low	Low

TABLE 4-22. YEARLY MAINTENANCE AND OPERATIONAL COSTS

Candidate Approaches \ Designs		Baseline System Design	Extended Baseline Designs For Increased Throughput			Alternative Baseline System Design
		• 40 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 100 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 175 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 250 Scenes/Day/Sensor • $\frac{\text{Sin}}{x}$ Resampling	• 40 Scenes/Day/Sensor • Resampling
<u>IBM</u> General Purpose Computer Approach	Manpower	$1.28M	$1.36M	$1.45M	$1.53M	$0.44M
	Spares and Consumables	$0.11M	$0.28M	$0.49M	$0.70M	$0.11M
	Total	$1.39M	$1.64M	$1.94M	$2.23M	$0.55M
<u>IBM</u>, <u>CDC</u>, and <u>GE</u> Special Purpose Approach	Manpower	$0.40M	$0.45M	$0.50M	$0.55M	$0.40M
	Spares and Consumables	$0.10M	$0.25M	$0.42M	$0.62M	$0.10M
	Total	$0.50M	$0.70M	$0.92M	$1.17M	$0.50M

TABLE 4-23. DELTA COSTS FOR ALTERNATE IMAGE PROCESSING SYSTEM REQUIREMENTS

Designs / Candidate Approaches	Instrument Configurations						Other Considerations		
	Thermatic Mapper (TM)		High Resolution Pointable Imager (HRPI)				UTM Projection	T/M% Oversampling	Input Format
	Honeywell	Te-Gulton	Westinghouse Linear Array	Hughes	Honeywell	Te-Gulton			
IBM General Purpose Computer Approach	*	*	**	**	**	**	+$0.3M	*	-$9.0M
CDC Flexible Processor Approach	+$0.3M	-$0.1M	**	**	**	**	+$0.25M	-$0.2M	-$0.1M
IBM Micro-Programmable Approach	*	*	**	**	**	**	+$0.30M	*	-$0.1M
GE Special Purpose Hardware Approach	+$0.3M	-$0.04M	-$0.06M	-$0.14M	+$0.12M	-$0.19M	+$0.30M	-$0.3M	-$0.1M

* Cost Data not Provided
** Impacted by timeliness of HRPI Instrument data availability

in cost than the other candidates. Therefore, the general purpose computer approaches were immediately eliminated from further consideration for EOS image correction.

Comparisons of the remaining three system configurations in Table 4-21 shows the GE special purpose hardware configuration to be the minimum cost approach for the baseline and alternate configurations at 40 scenes/day as well as all extended baseline configurations at the 100, 175 and 250 scenes/day throughput rates. All three configurations are relatively insensitive to the resampling technique employed with the CDC having the highest cost delta of approximately $0.35M at 40 scenes/day throughput. The CDC approach is also considerably more cost sensitive to throughput (having a $3.15M cost delta compared to $0.74M for IBM and $0.92M for GE for an increase from 40 to 250 scenes/day). The actual manner in which costs increase with throughput is illustrated in Figure 4-24. The yearly maintenance and operational costs, shown in Table 4-22, are approximately the same for all three approaches. The risk involved in development is not a major factor for any approaches.

Impact of Alternative Performance Requirements

Impact of Thematic Mapper Instruments

The major cost impact parameters of the Thematic Mapper Instruments are the scan philosophy and the band-to-band mis-registration. The delta implementation costs due to these parameters are shown in Table 4-24 with the Hughes Oscillating Mirror Scanner selected as the reference baseline. The Hughes scanning approach has a $40K cost impact due to the back and forth scan as compared to the Te Gulton instrument. The Honeywell Conical scan has a $300K greater impact, as compared to the Te Gulton due to the additional storage required to linearize the data into straight lines. The Honeywell instrument has a $40K cost increase, over the other two instruments, to achieve band-to-band registration due to the offset of band 7 perpendicular to the scan direction rather than along the scan direction. Parameters such as scan linearity, data formats,

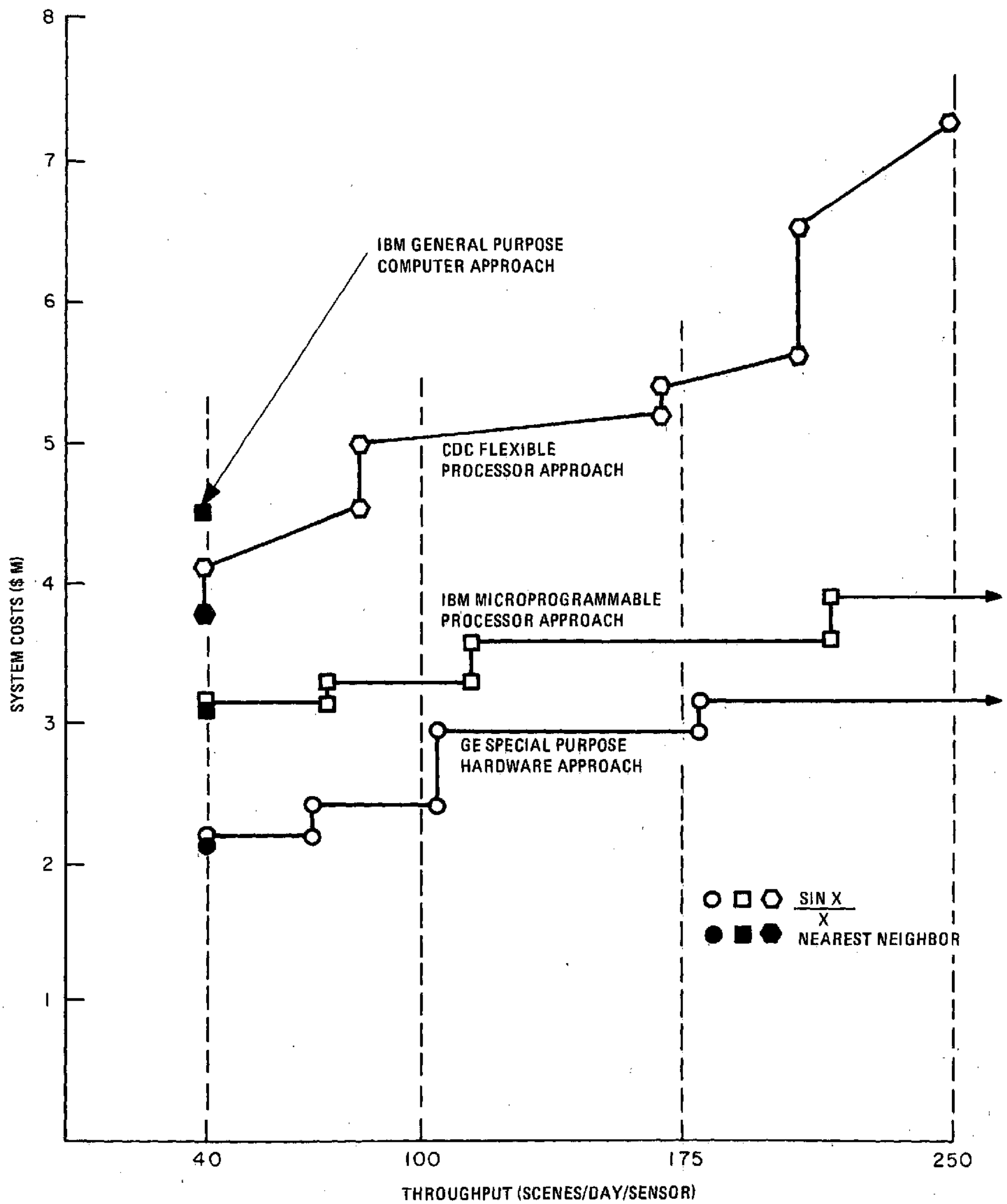


Figure 4-24. Comparison of Baseline System Design Costs over Throughput Range

TABLE 4-24. COST IMPACT OF THEMATIC MAPPER INSTRUMENTS

Instrument	Scanning Philosophy	Band-to-Band Registration	Cost Normalized to Reference Baseline
Hughes	+$40K	0	Reference
Honeywell	+$300K	+40K	+$300K
Te Gulton	0	0	-$40K

radiometric accuracy, etc., do not impact the Digital Image Correction Subsystem cost providing the TM instrument manufacturer meets the specifications for accuracy and stability.

Impact of HRPI Instruments

The major cost impact factors for the HRPI instruments are band-to-band registration data format, linearity, radiometric banding and radiometric accuracy. The delta implementation costs due to these parameters are shown in Table 4-25 with the Westinghouse Staggered Array selected as the reference baseline.

All instruments except the Hughes are band-to-band registered. The data format cost impact includes the various scanning approaches. The staggered pushbroom array is the most expensive because of the need to buffer extra lines of data to fill the gaps and complete a line. Linearity includes the cost impact of removing the non integral pixel spacing in the Westinghouse Pushbroom Arrays, as well as the cost impact of the Honeywell conical scan. The radiometric accuracy (both relative and banding) is more expensive for the Westinghouse HRPI's due to the large number of detectors requiring correction.

Impact of Output Projections. The cost impact in implementing the UTM projection alternative is due to the storage of data necessary to account for the maximum rotation angle between the input scan line and output grid line. The cost impact is approximately

TABLE 4-25. COST IMPACT OF HRPI Instruments

	Band-to-Band Registration	Data Format	Linearity	Radiometric Banding	Radiometric Accuracy	Total
Westinghouse Stagger Array	0	0	0	0	0	0
Westinghouse Linear Array	0	-60K	0	0	0	-60K
Hughes	+20K	-30K	-45K	-65K	-15K	-135K
Honeywell	0	-60K	+255K	-65K	-15K	+115K
Te Gulton	0	-60K	-45K	-65K	-15K	-185K

the same for each alternative design configuration and therefore is not a factor in the system design selection. A cost tradeoff does exist between performing UTM projection transformation in the on-line processing or in the off-line processing. Based on the anticipated throughput requirement for the UTM projection data ($\sim$6 scenes/day), and the cost advantage of performing the transformation off-line ($300K vs. 75K), the off-line UTM projection transformation is considered the baseline.

Other Impacts.

The cost impacts due to the input format and oversampling alternatives are not significant factors in comparative evaluation of the three special hardware approaches. Data format does have a major impact on the general purpose approach, but the cost savings is still not sufficient to make this a viable candidate approach.

The results of these impacts are utilized in system level cost trades for bandwidth (Section 2.16) and on-board vs. ground processing (Section 2.17).

Conclusions

Based on the design/cost data presented above, the following conclusions can be drawn:

- The IBM General Purpose Computer approach is not a viable candidate; this approach is still significantly higher in cost than the other approaches even if only nearest neighbor resampling technique is utilized.
- The CDC Flexible Processor approach is the highest in cost of the other three configurations and is quite sensitive in cost to increased throughput.
- The IBM Micro-Programmable Processor approach and the GE Special Purpose Processor approach are viable candidates; the cost differences vary from \$0.6M to \$0.9M depending on throughput, in favor of the latter approach. The tradeoff of cost vs. flexibility has not yet been fully evaluated. The remainder of the study will concentrate on further design, cost and performance analysis of the GE and IBM approaches.

4.3.4.2 Custom Off-line Processing

Digital Tape Generation Design/Cost Tradeoffs

Requirements Summary

The requirements for the digital tape generation function are summarized on Table 4-26.

TABLE 4-26. DIGITAL TAPE GENERATION REQUIREMENTS

Input	Function	Throughput	Output
HDDT	• HDDT Generation - Copy only - Pixel reformatting - Resolution reduction - MTF compensation - Digital enlargement	300 to 1240 scenes/day	HDDT - Standard format and packing density
	• CCT Generation - Custom projection - Copy only - Pixel reformatting - Digital enlargement - Resolution reduction - MTF compensation	15 to 50 scenes/day	CCT - Standard format - 1600 and 6250 bits/inch packing density

The design and implementation of the digital tape generation subsystem is based on the maximum utilization of the equipment (primarily recorders) to meet the specified throughput requirements to minimize total cost. The basic subsystem configuration for HDDT and CCT generation is shown on Figure 4-25. The HDDT generation subsystem is designed to produce multiple copies of tapes while the CCT generation subsystem is configured to perform custom processing functions and produce CCT's as its normal output. However, the CCT generation system will be capable of writing on an HDDT the same custom processed data for use by the Film Image Generation and Processing Subsystem.

Computer Compatible Tape Generation Design/Cost Tradeoffs

General

In the EOS-A era, it is assumed that most EOS users/investigators will have the capability to utilize CCT's having a packing density of 1600 Bpi while the larger users/investigators will have the capability of handling 6250 Bpi packing densities. Therefore, the CCT generation function has been designed to have the capability of generating tapes in both packing density formats.

The 6250 Bpi packing density will permit one HRPI scene (all 4 bands) or one TM scene (all 7 bands) to be recorded on two standard length computer compatible tapes of 2400 feet each; reducing the packing density to 1600 Bpi will increase the number of tapes to eight for either a HRPI or TM scene.

Since two CCT's, with 6250 Bpi packing density, are required for one scene, the option exists to record on each tape the full scene width by one-half the scene length or one half the scene width by the full scene length. The latter option permits the utilization of two output CCT recorders, to record the full scene content on one pass and increase the throughput accordingly at a minimum cost increase (one additional recorder plus some buffering of the output data and switching).

The same approach is also applicable for the 1600 Bpi packing density. Since eight tapes are required for one scene, each tape could record one-eighth of the scene width by the full scene length and reduce the number of passes required as a function of output CCT recorders (one pass with eight output CCT recorders, two passes with four output CCT recorders and four passes with two output CCT recorders).

"Copy Only" Mode Considerations

The block diagram of the basic hardware configuration for producing computer compatible tapes (1600 and 6250 Bpi) from HDDT's in the "copy only" mode is shown on Figure 4-25.

The reformatter is a minicomputer with sufficient memory, buffering capabilities and speed to fully utilize the writing data rate of the CCT controller and tape units.

The cost vs throughput for various configurations satisfying the 1600 Bpi and 6250 Bpi packing density formats are shown on Figure 4-26. The addition of the second recorder for the 6250 Bpi format provides a 57% increase in throughput (35 scenes/day increased to 55 scenes/day) at a cost increase of 22% (160K increased to 195K). Similar conclusions are applicable for the 1600 Bpi format configuration also.

Figure 4-27 provides a mix possibility for systems that utilize the same equipment for copying both the 1600 Bpi and 6250 Bpi CCT's. Configuration B, employing two output CCT recorders, is the most cost effective solution and provides a throughput of 34 scenes/day which is considered acceptable for this system.

"Custom Process" Mode Considerations

In addition to reformatting and CCT copying, the remaining functions listed in Table 4-26 are also performed. Implementation of these functions is accomplished with special purpose modules using a combination of special hardware and the general purpose reformatting mini-computer.

The approximate cost associated with each function is shown in Table 4-27. The total CCT generation subsystem hardware cost, excluding the output HDDT recorder which is part of the HDDT generation subsystem, is $320K.

UTM Projection Tradeoffs

The most demanding and costly function is the processing of data in other than the standard SOM output projection. For purposes of costing the CCT generation subsystem design, the UTM projection system was chosen with a consistant reference grid angle

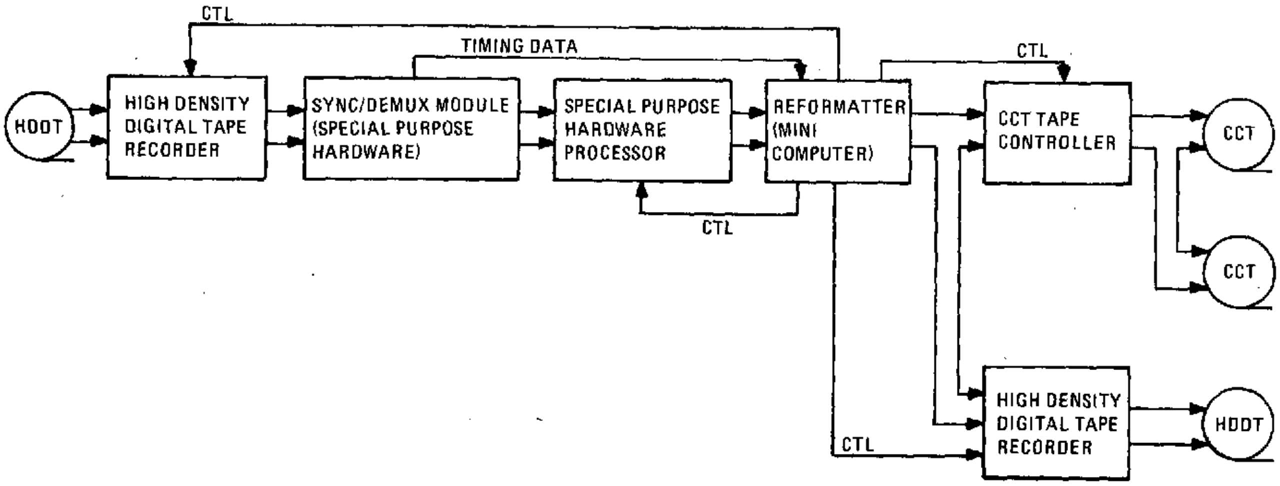


Figure 4-25. CCT Generation System Block Diagram

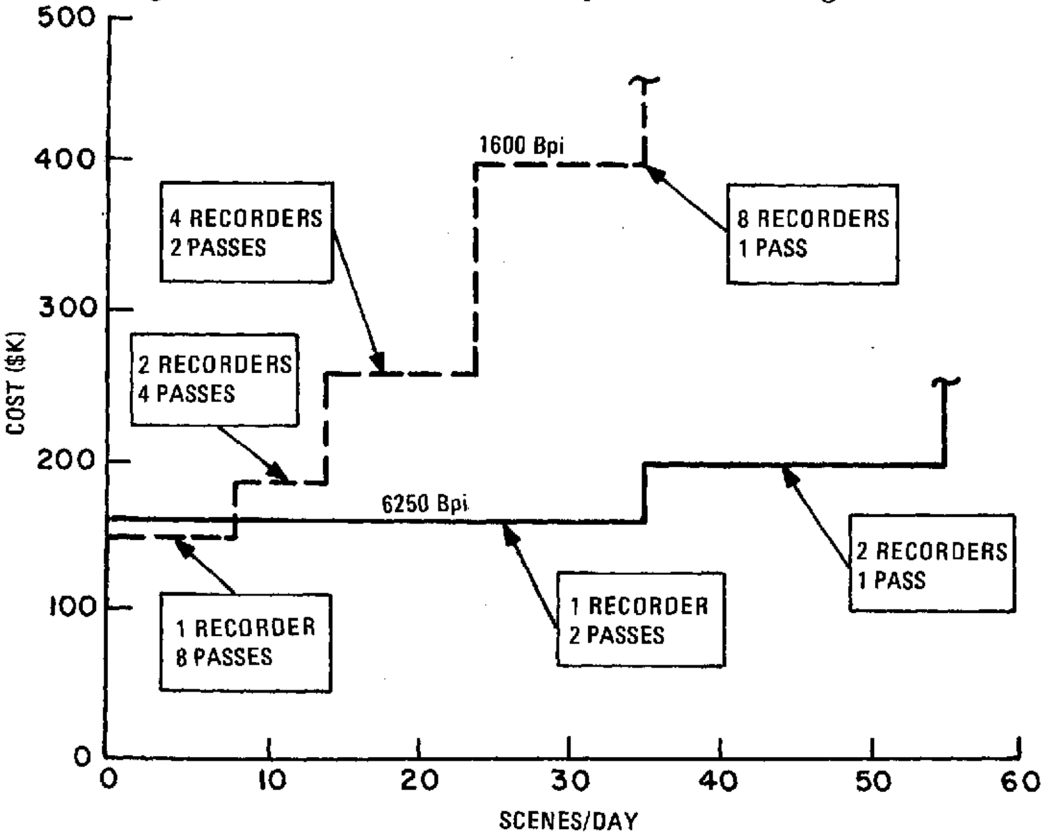


Figure 4-26. CCT Generation Subsystem Hardware Costs Vs. Throughput (Reformatting and CCT Copying Only)

CONFIGURATION/ NO. OUTPUT CCTR's		THRUPUT* (SCENES/DAY			COST ($ K)	COST/THROUGHPUT ($ K/SCENES/DAY)
		1600 Bpi	6250 Bpi	TOTAL		
A	1	4.0	17.5	21.5	160	7.44
B	2	6.5	27.5	34.0	195	5.75
C	3	12.0	27.5	39.5	270	6.84
D	4	20.0	27.5	47.5	410	8.61

*ASSUMES EQUAL TIME FOR 1600 Bpi AND 6250 Bpi CCT GENERATION

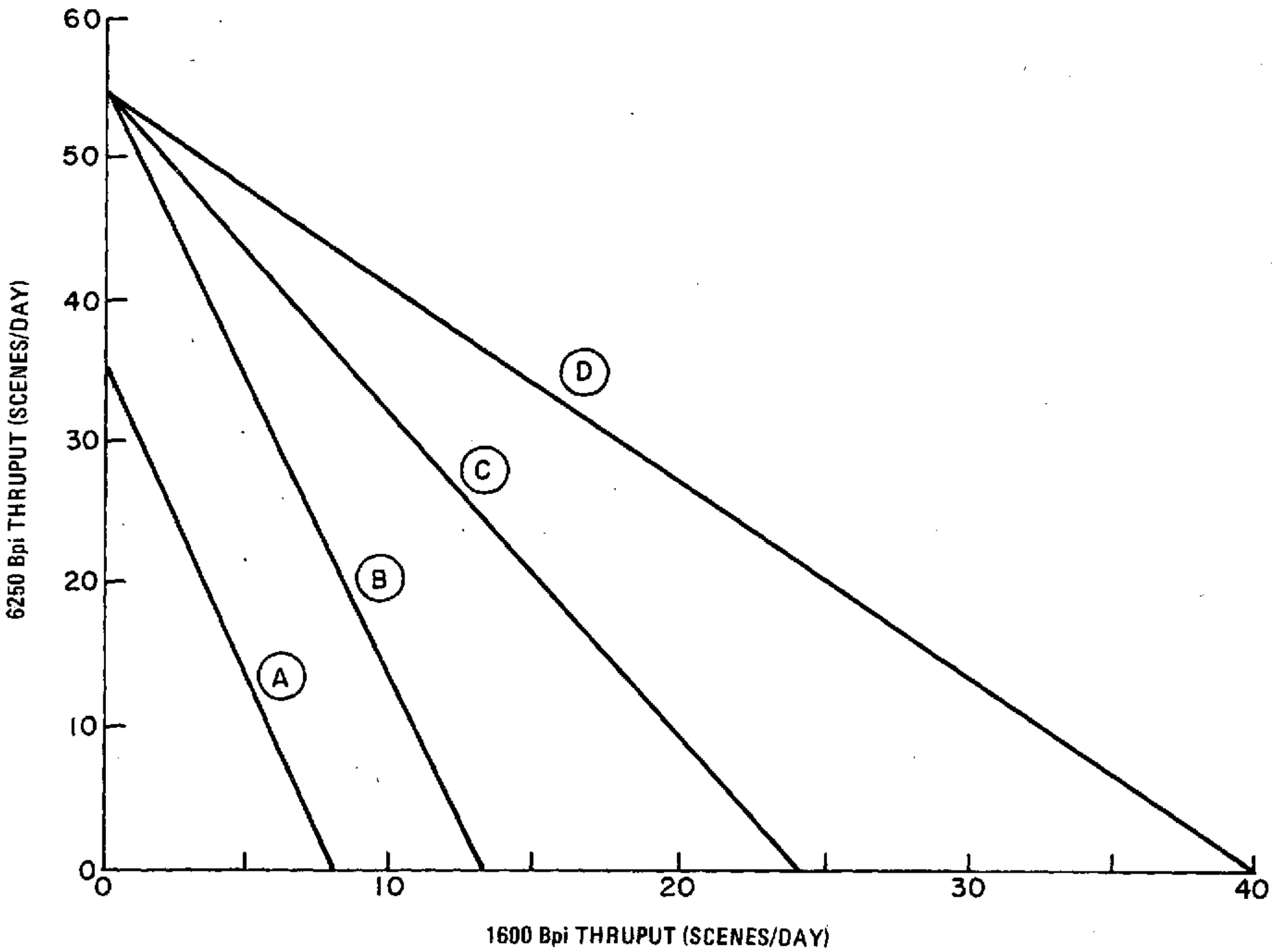


Figure 4-27. Possible Mix of 1600 and 6250 Bpi Throughput

TABLE 4-27. CCT GENERATION SUBSYSTEM COST

Function	Cost ($ thousands)
Basic CCT Copying	$195
Digital Enlargement	8
UTM Projection	75
Resolution Reduction	3*
Area Reduction	2
MTF Compensation	20*
Pixel Reformatting	4
Digital Reformatting	7
HDDT Interface	6
	$320

*Assumes UTM Projection capability exists, otherwise costs will be higher

over the entire U. S. (24° to 50° North Latitude). The major cost item in this processing function is the buffer memory necessary to store several lines of data and perform an angular rotation between the input data scan lines and the output grid line. However, since the projected data throughtput is low (~ 6 scenes/day) a cost tradeoff can be made between the number of passes through the data to correct the scene and the amount of memory required.

This is accomplished by sectoring the image which reduces the buffer memory cost by the square of the number of sectors selected. Figure 4-28 is a plot of memory cost verses the number of sectors for the EOS-A sensors (TM is limiting). The total system cost will be minimum at four to five sectors since at higher sectors the cost increase due to the increased control and sequencing logic necessary to recombine the data into images will outweigh the cost decrease due to further buffer memory reduction. The baseline system design concept selected is to sector the image into four equal areas parallel to the along-track direction. Each sector will be converted into the UTM projection individually and recorded on a 6250 Bpi CCT recorder reducing the throughput

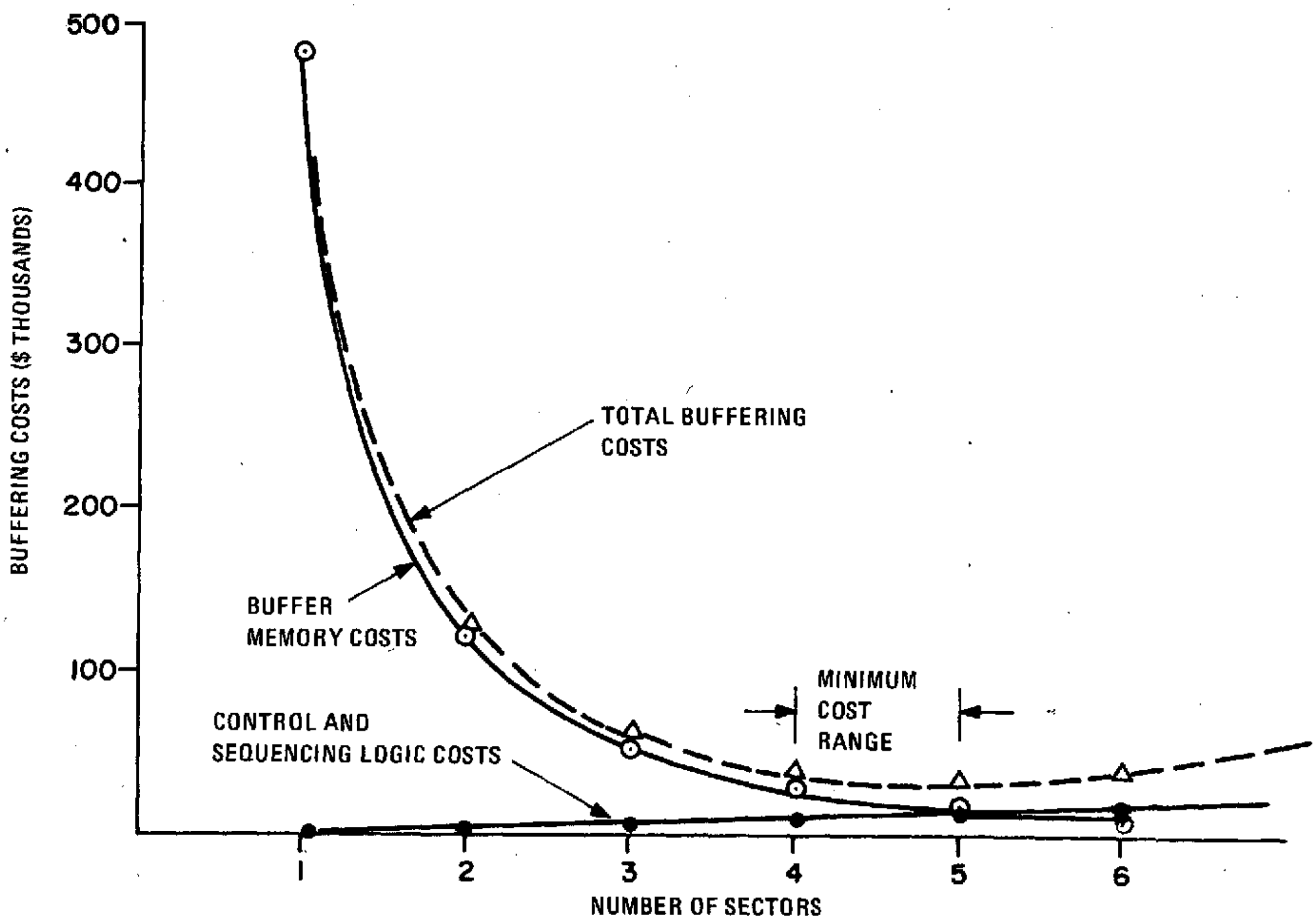


Figure 4-28. Buffering Cost Vs. Number of Sectors

by a factor of two. The procedure is as follows: Sector 1 is run and recorded on one CCT followed by Sector 2, however, the CCT containing Sector 1 will be played back and recombined with Sector 2 and formatted as a conventional 1/2 Sector on the second CCT recorder. Therefore two passes thru the data produces one CCT containing one-half of the image (sectors 1 and 2) converted into the UTM format. Two additional passes will produce the remaining two sectors on a second CCT.

When the custom processing output is to be on a HDDT, a fifth pass is required to combine the outputs of the two CCT's generated above onto a HDDT. If the final requirements for the CCT generation subsystem begin to impose throughput problems due to the required number of passes thru the data associated with the UTM Projection function, the sector division could be reduced from 4 to 2. This will reduce the number of passes for CCT generation from four passes to two and for HDDT generation from five passes to two at a cost increase to the CCT generation subsystem of approximately $90K.

High Density Tape Generation Design/Cost Tradeoffs

General

The primary purpose of the HDDT generation subsystem is to produce multiple copies of both U. S. and non-U. S. data for distribution to major data users (e. g., Sioux Falls Data Center, Department of Agriculture, United Nations Distribution Center, etc.). For the purpose of the associated tradeoffs, the maximum number of copies distributed to major users is assumed to be 4 for non-U. S. data and 10 for the U. S. data.

The block diagram of the basic hardware configuration for copying high density digital tapes is shown in Figure 4-29.

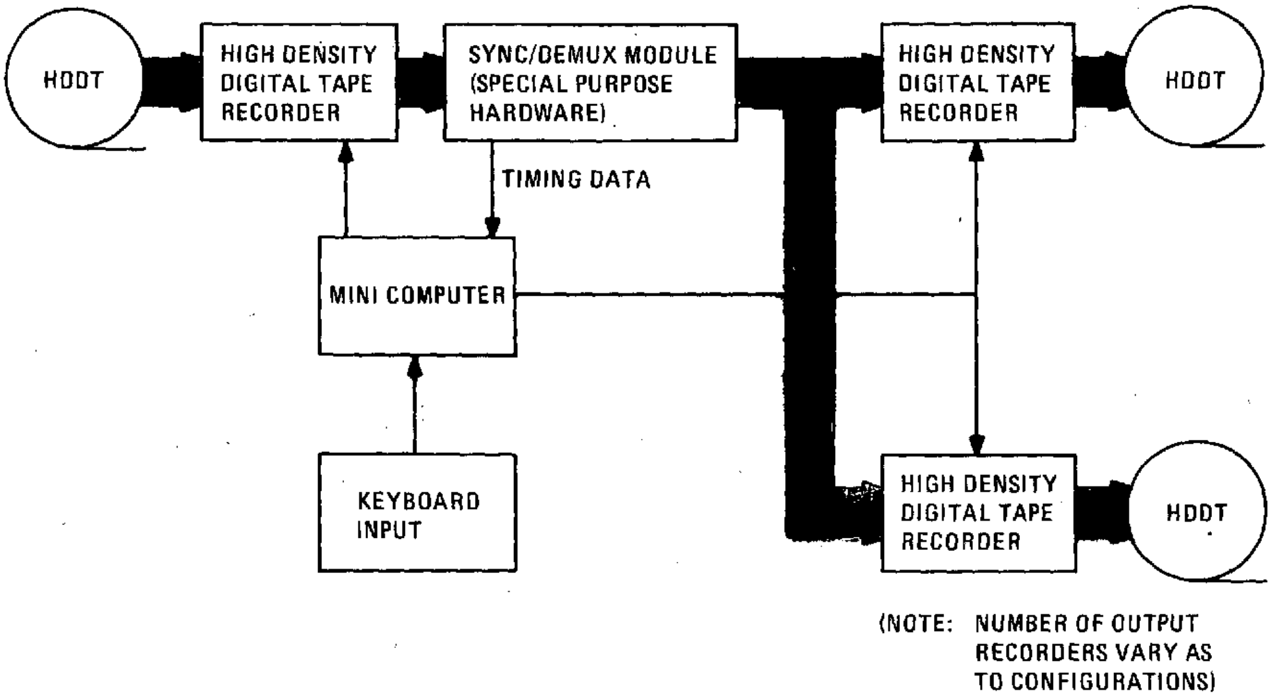


Figure 4-29. HDDT Generation System Block Diagram

Tradeoff Data

Figure 4-30 presents the throughput capability of various configurations for the HDDT generation subsystem in terms of possible number of copies for U.S. data and non-U.S. data for a throughput of 40 and 210 scenes/day respectively.

Configurations A, B and C process the information data at real-time rates and utilize 1, 2 and 3 120Mb/s HDDT output recorders respectively. Configurations D and E process the information data at approximately one-half (0.46) the real-time information data rate and utilize 3 and 4 40Mb/s HDDT output recorders respectively. These curves assume a 16 hour processing day at 70% operating efficiency and include both Thematic Mapper and HRPI data.

INFORMATION DATA RATE	CONFIGURATION/ OUTPUT HDDTR's		COST ($K)
REAL TIME	A	1	350
	B	2	500
	C	3	650
~ 46% REAL TIME	D	3	320
	E	4	360

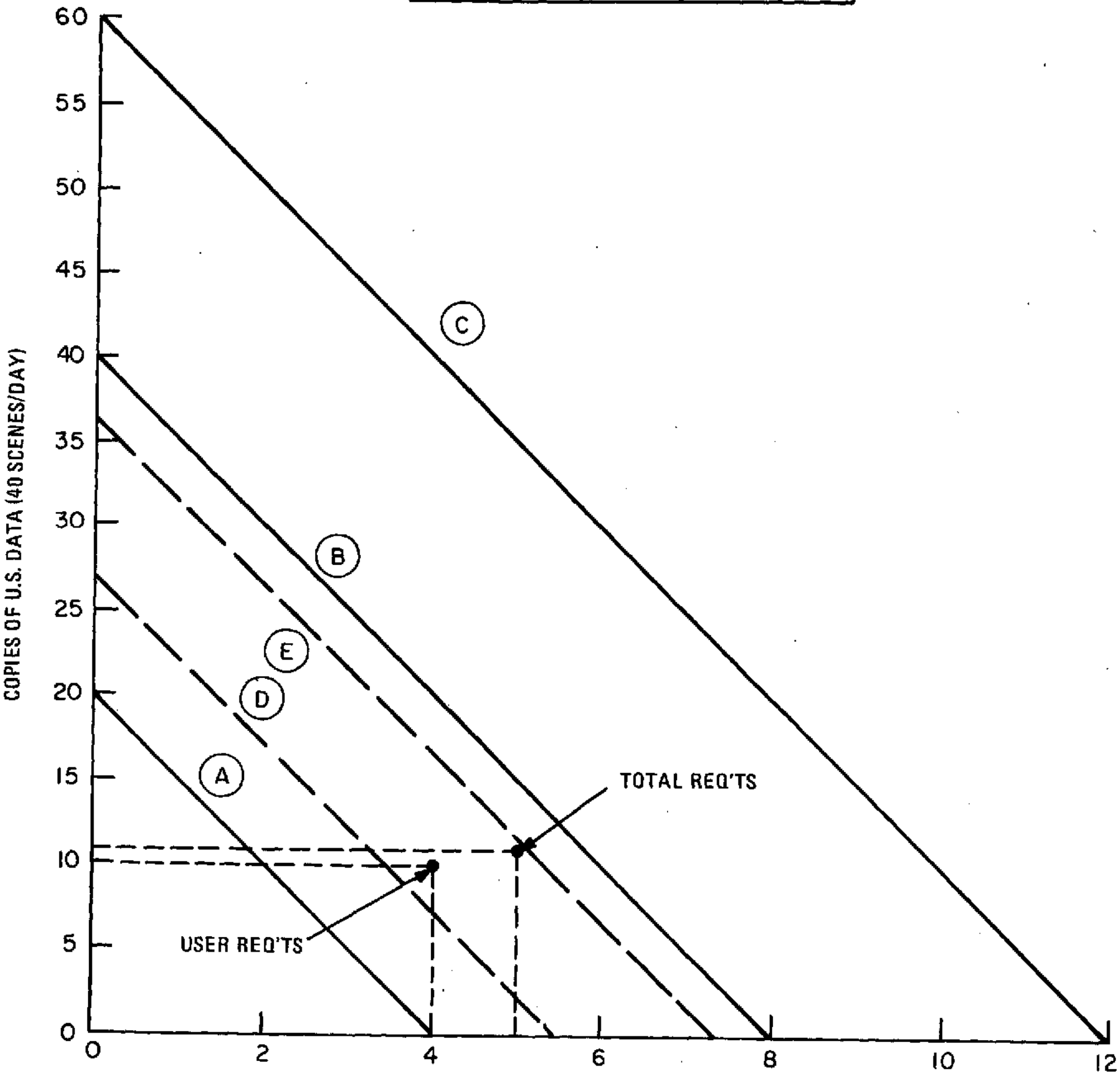


Figure 4-30. Possible Number of Copies of U. S. and Non-U. S. Data

Tradeoff Discussions

The major cost difference between the configurations is the type of recorders (120 Mb/s or 40 Mb/s) utilized and the total number of recorders required. Only configurations B, C and E satisfy system throughput requirements; configuration E is the preferred approach on the basis of cost. It also has the advantage of reducing the cost to the major users since their recorders need be of the 40 Mb/s type rather than the more expensive 120 Mb/s type.

To minimize the total cost of the Image Processing Element, the custom off-line functions were configured to use the 40 Mb/s type recorder also. Since the output recorders for the standard on-line functions, for system thruput rates exceeding 100 scenes/day, require the use of 120 Mb/s output recorders, the HDDT Generation Subsystem must provide an additional copy of both U.S. and non-U.S. data for internal use within the IPE. Configuration E satisfies this additional requirement.

Impact of System Throughput

The total number of scenes generated by the HDDT Generation Subsystem is a function of system throughput. Figure 4-31 plots the total number of scenes to be generated (copied) as a function of system throughput over the range from 40 to 250 scenes/day. Also shown is the capability and cost of the HDDT Generation Subsystem with output recorders varying from 1 to 4. At a system throughput rate of 175 scenes/day only three output recorders are required; at system thruput rates of 40 and 100 scenes/day only two output recorders are required. If the requirement of 10 copies of U.S. data is reduced to 9, only one output recorder would be required.

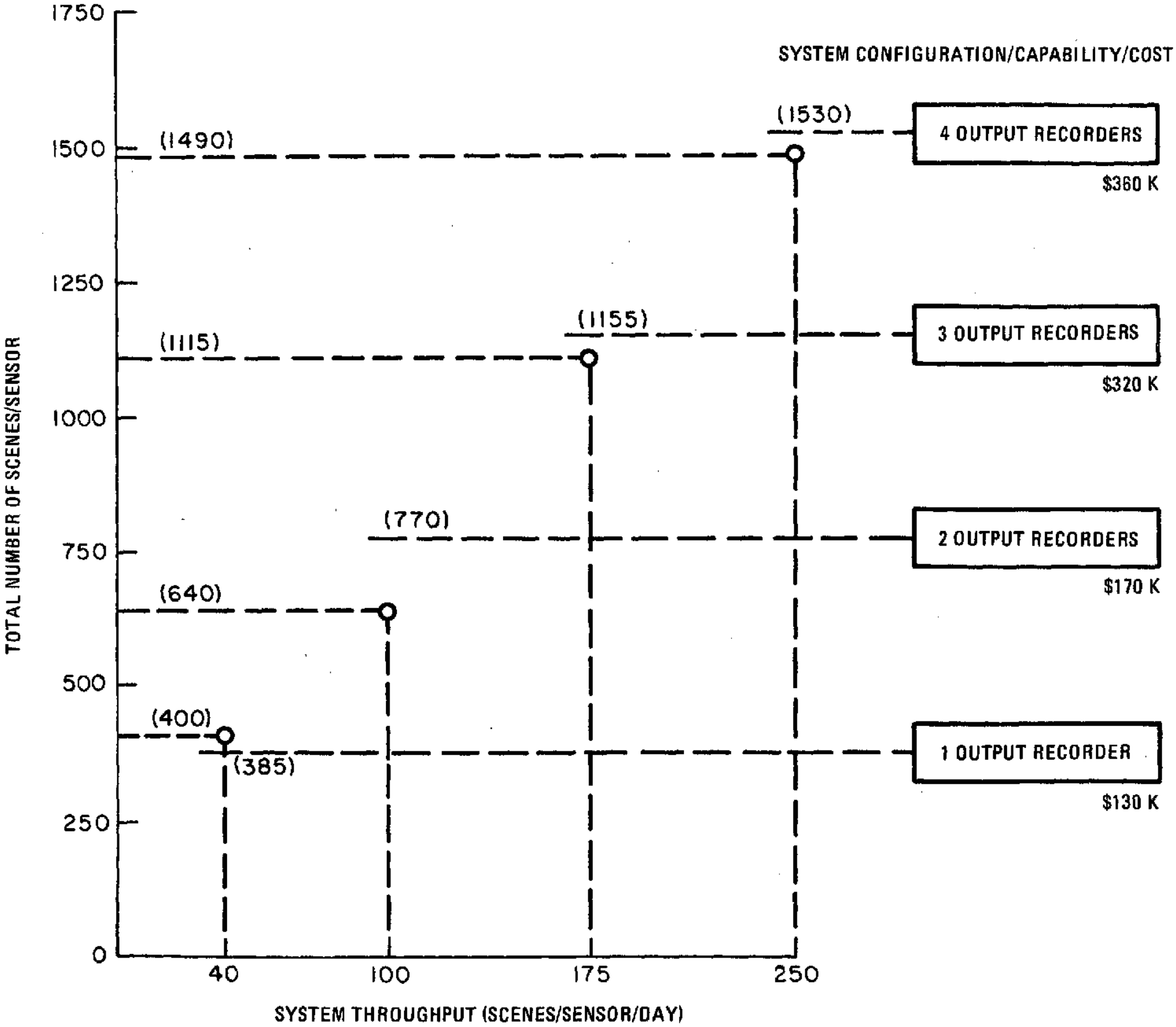


Figure 4-31. Total Number of Scenes Vs. System Throughput

Film Image Generation and Processing Design/Cost Tradeoffs

Requirements Summary

The requirements for film image generation and film processing are summarized on Tables 4-28 and 4-29 respectively. The film image generation function will require new equipment; the film processing function is basically satisfied by the present ERTS Photo Lab.

Film Image Recorder Selection and Characteristics

Recorder Selection

Many studies have been made to select the better image recorder between two leading candidates — the election beam recorder (EBR) and the laser beam recorder (LBR). The significant conclusions from these studies are:

- Both candidates can write 8,000 to 10,000 pixels per line with an accuracy of 0.1 to 0.3 pixels.
- Both candidates can operate with 10 to 20 MHz writing bandwidths
- EBR has electronic scan agility advantages and can introduce geometric corrections; LBR has the constraint of a raster scan
- LBR has the advantage of larger image format (9.5 inch wide film) in operation; ERB breadboard model has been demonstrated at a 5-inch wide format with statements that an ERB with 9.5-inch wide format is feasible.

The EOS Specification for the System Definition Studies requires that the basic processing of image data, i.e., geometric correction, radiometric calibration, etc., shall be performed digitally; this requirement removes the EBR electronic scan agility advantage. This specification also requires that the first generation product be of

TABLE 4-28. FILM IMAGE GENERATION REQUIREMENTS

Input	Function	Throughput	Output
• Direct On-line input from Digital Image Correction Subsystem	• Catalog Film Image Generation	• 40 to 250 scenes/day/sensor	• 1st generation film strip for photo copying → (A)
• HDDT	• Custom Off-line Film Image Generation (1st generation) - Standard Map Scale TM - $1{:}1 \times 10^6$ HRPI - $1{:}0.5 \times 10^6$ - $1{:}0.25 \times 10^6$ (option) - Photographic gamma change	• 20 to 200 scenes/day/sensor	• 1st generation 9.5" film images - for direct distribution to users and/or - for 2nd generation products → (B)

TABLE 4-29. FILM PROCESSING REQUIREMENTS

Input	Function	Throughput	Output
(A) → 1st generation film strip	• Photo Copying	• 2 to 10 copies	• 1st generation film strip to archive • 2nd generation film strip to major user
(B) → 1st generation film images	• Custom Off-line Color Film Generation - false color mix		• 2nd generation 9.5" color film images - for direct distribution to users and/or - for generation of 3rd generation products → (C)
	• Custom Off-line B/W Film Photo Copying (2nd generation) + Prints) - Standard Map Scale TM - $1{:}1 \times 10^6$ HRPI - $1{:}05 \times 10^6$ - 2X and 4X Enlargement TM - $1{:}0.5 \times 10^6$ and $1{:}0.25 \times 10^6$ HRPI - $1{:}0.25 \times 10^6$ and $1{:}0.125 \times 10^6$	• 40 to 400 scenes/day • 220 to 2200 images/day (equal TM and HRPI scenes assumed)	• 2nd generation film and prints for direct distribution to users
(C) → 2nd Generation color film images	• Custom off-line Color Film Photo Copying (3rd generation) and Prints - Standard Map Scale TM - $1{:}1 \times 10^6$ HRPI - $1{:}0.5 \times 10^6$ - 2X and 4X Enlargement TM - $1{:}0.5 \times 10^6$ and $1{:}0.25 \times 10^6$ HRPI - $1{:}0.5 \times 10^6$ and $1{:}0.125 \times 10^6$	• 10 to 100 scenes/day	• 3rd generation film and prints for direct distribution to users

9.5-inch width suitable for 1:1 x 10^6 standard map scale; this latter requirement favors the LBR since units with this width are operational.

Both RCA and CBS have operating laser beam recorders. RCA has an off-the-shelf laser beam recorder that uses 9.5-inch wide film; CBS is doing development work at this size. The RCA laser beam recorder will be used as the baseline recorder in this definition of the Film Image Generation and Processing Subsystem and the associated design/cost trade-offs.

RCA Laser Beam Image Recorder Characteristics

The primary characteristics of the RCA LBIR are:

- Spot Size - 10 micron diameter
- Line Rate - up to 350 line/second
- Video Writing Speed - 15 pixels/μ second (standard)
  - 30 pixels/μ second (maximum)

The effective spot size can be increased by reducing the pixel clock time by some integer and using the integer to increase the number of recorder lines per picture. Figure 4-32 provides a summary of these characteristics. Maximum line rate can not be achieved with effective pixel sizes of 10 and 20 microns with a video writing speed of 15 pixels/μ second. Increasing the video writing speed to 30 pixels/μ second (at a delta cost of $20K/recorder) removes the limitation on the 20 micron effective pixel size and increases the line rate from 118 lines/second to 236 lines/second for the 10 micron pixel size.

The effect of increasing the video writing speed from 15 to 30 pixels/μ second reduces by 1/2 the image time for the catalog film for both the HRPI and TM images (which uses the 10 micron spot size) as well as reduce by 1/3 the image time for the custom HRPI images (which uses the 20 micron spot size). The baseline assumes the higher video writing speed.

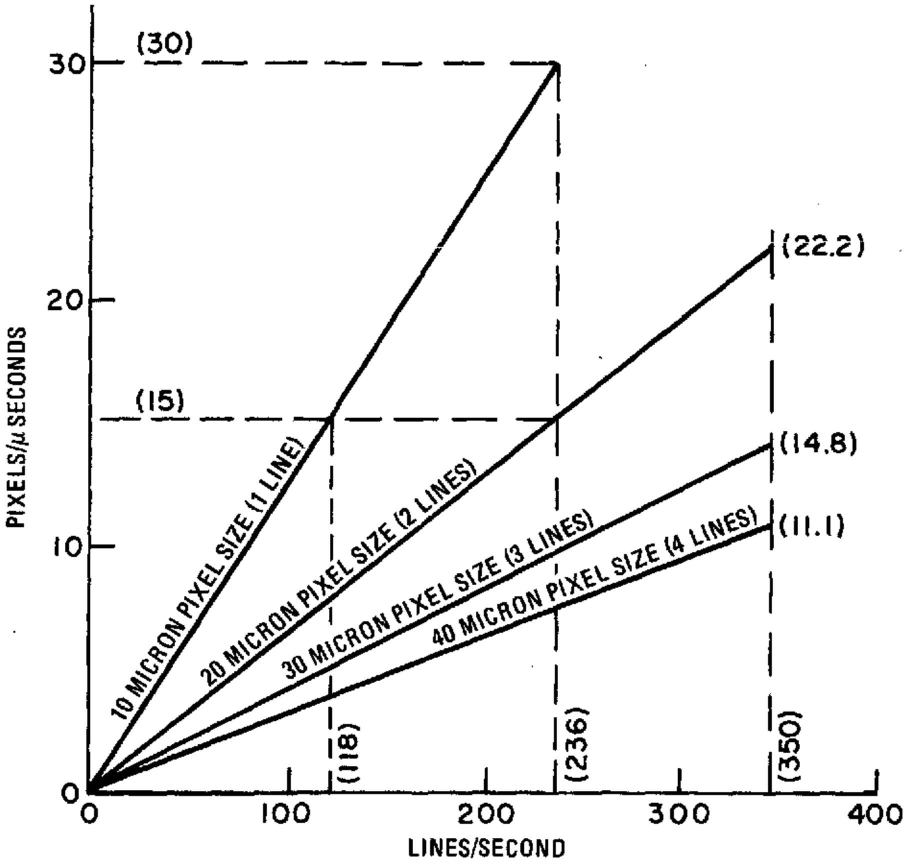


Figure 4-32. Laser Beam Image Recorder Characteristics

The characteristics for the TM and HRPI catalog and custom images are presented on Table 4-30; data from this table will be used in the design/cost trade-offs.

TABLE 4-30. TM AND HRPI IMAGE CHARACTERISTICS

Image Type	Effective Pixel Size	Pixels / μsecond	Lines / seconds	Image Time (seconds)	Image Size	Map Scale	
TM Catalog	10 microns	30	236	26.2	2.4"x2.4"	1:3 x 10^6	Baseline
HRPI Catalog(1)	10 microns	30	236	78.6	1.9" to 2.9"x7.2"	1:1 x 10^6	↓
TM Custom	30 microns	14.8	350	53.0	7.2"x7.2"	1:1 x 10^6	
HRPI Custom(1)	20 microns	22.2	350	106.0	3.8 to 5.8"x14.4"	1:0.5 x 10^6	
HRPI Custom(2)	40 microns	11.1	350	212.0	6.6 to 7.2"x28.8"	1:0.25 x 10^6	Option

Notes (1) Image size with pointing angle up to 32°
(2) Image size with pointing angle up to 20°

The first generation HRPI Custom Image has a map scale of 1:0.5 x 10^6, has an image length of 14.4 inches and exceeds the normal standard image presentation size; this can be corrected by splitting the scene in half and in effect producing two custom images per HRPI scene requiring 53 seconds of image time each.

Desgin/Cost Tradeoff

The cost of the film image generation function/equipment is dependent on the system throughput requirements and the information flow within the Image Processing Element. Two alternatives are defined below and their costs as a function of system throughput provided.

Description of Alternative #1

A block diagram for this configuration is presented on Figure 4-33. One LBIR is dedicated to the standard on-line processing function for generation of the catalog film images and a number of LBIR's provided to generate the custom off-line film images. The number of LBIR's required, to satisfy this last requirement, is a function of the system throughput requirements divided by the throughput of the individual LBIR's.

The maximum throughput of an LBIR, assuming 100% utilization for a period of 40,000 seconds is 43 scenes since:

- a T/M scene includes 7 images (one per band) requiring 62 seconds/image (53 seconds for a scene plus 9 seconds for overlap and annotation requirements)
- a HRPI scene includes 8 images (one per band multiplied by 2 for splitting the scene in half) also requiring 62 seconds each, and
- a scene is defined to include both T M and HRPI images or a total of 15 images requiring utilization of an LBIR for 930 seconds

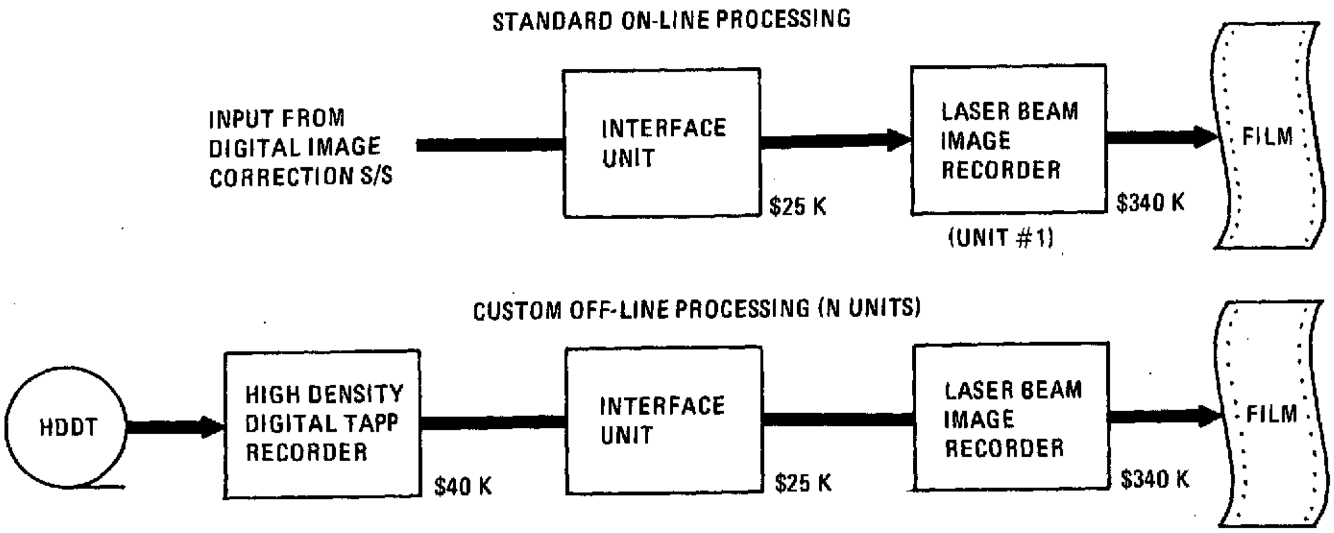


Figure 4-33. Film Image Generation Block Diagram (Alternate #1)

Since the LBIR must be reloaded with new film and serviced, the utilization was reduced to 90 to 95% which reduces throughput to 40 scenes/day. Also, considering that the scene data on the HDDT's is not efficiently packed from an LBIR utilization viewpoint (band interleaved and only selected scenes required), searching, rewind, researching, etc. will further reduce the utilization of the LBIR an additional 50 to 60% which in turn reduces throughput to approximately 22 scenes/day or 330 images/day.

Utilizing the 22 scenes/day throughput for the individual LBIR's, the number of LBIR's required and the cost for the Film Image Generation Subsystem as a function of throughput for the range of 20 to 200 scenes/day is plotted on Figure 4-34.

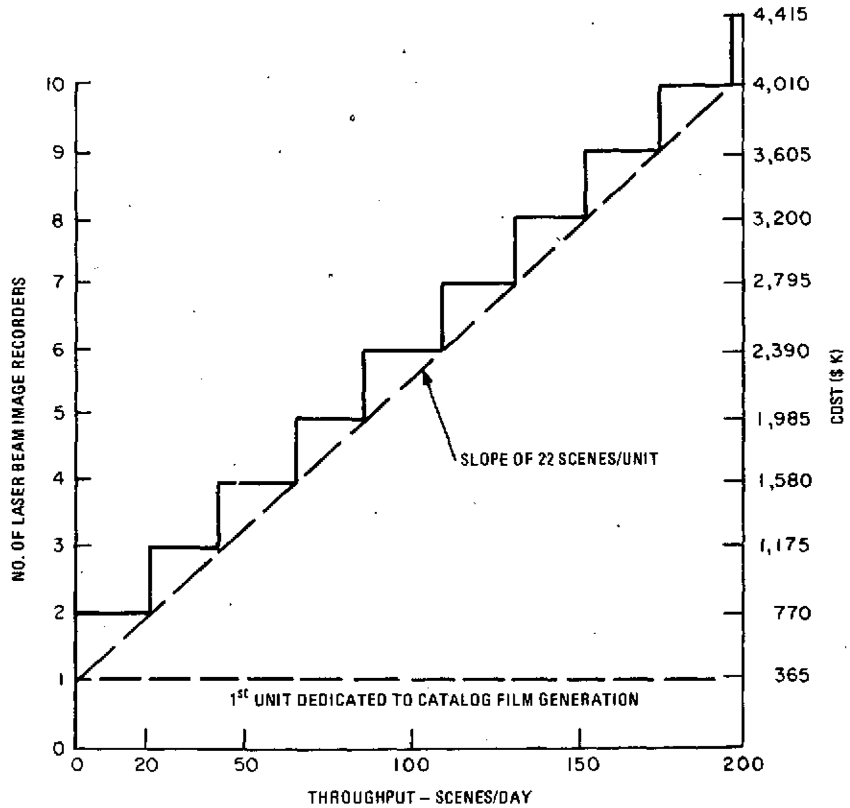


Figure 4-34. Throughput Vs. Number of Recorders and Cost (Alternate #1)

Description of Alternative #2

The major disadvantage of the first alternative is the:

- low utilization of the LBIR dedicated to perform the standard on-line generation of the catalog film images and,
- the low operating efficiency of the individual LBIR's due to the data arrangement of the HDDT's.

A block diagram for the second configuration is presented on Figure 4-35. In this alternative the image data associated with the catalog film is first recorded on an HDDT and then processed on an available LBIR thereby removing the inefficiency of the dedicated LBIR at the expense of an additional HDDT for the Digital Image Correction

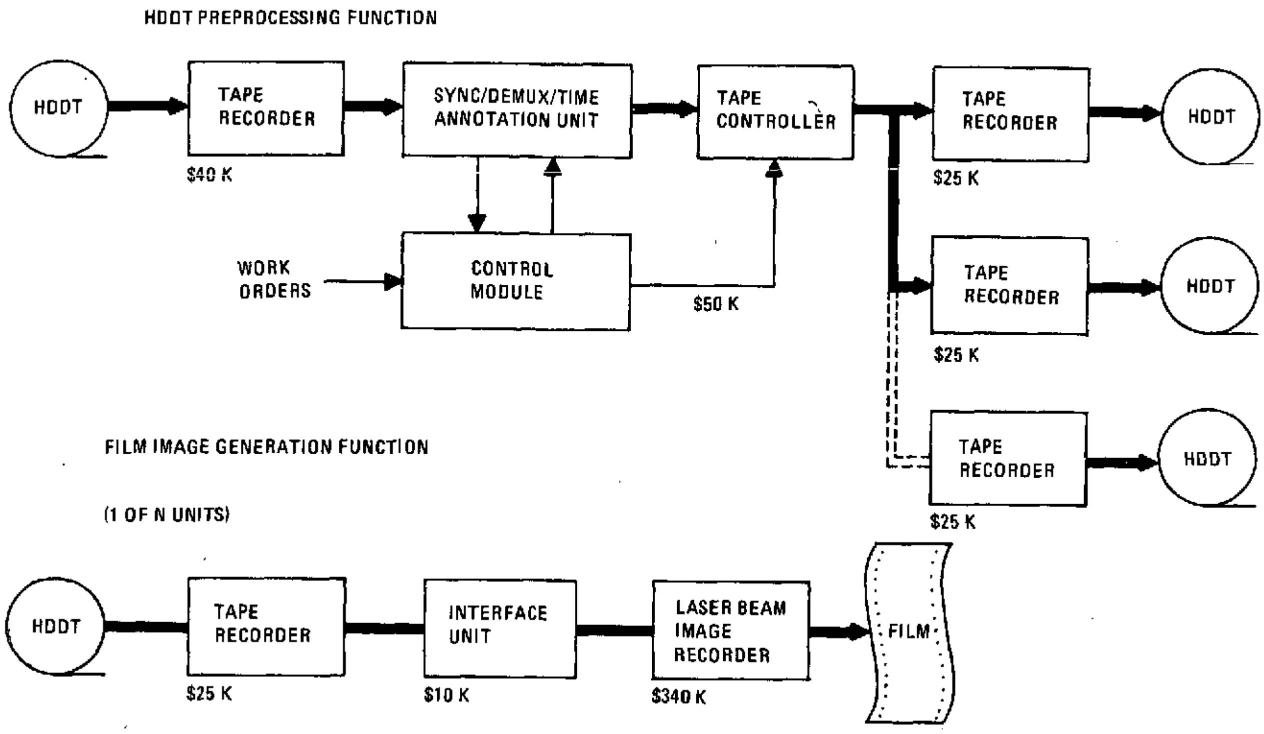


Figure 4-35. Film Image Generation Block Diagram (Alternate #2)

Subsystem. The other major change is the addition of an HDDT Preprocessing Subsystem which selects the image data according to work order requirements and places only the data to be processed on the output HDDT's in a band non-interleaved format for the individual images. Since one HDDT will contain a large number of images the operating efficiency of the LBIR's can approach the throughput rate of 40 scenes/day discussed earlier. The throughput of the HDDT Preprocessing for converting the data into the proper LBIR input format was established at 165 scenes/day based on reduced TM and HRPI input data rates and utilizing a 55% efficiency factor. This configuration utilizes 4 HDDT recorders at the output requiring two passes for each of the HDDT's containing the TM data to separate the individual bands for each of the desired scenes and one pass for the HDDT's containing HRPI data.

By increasing the output HDDT recorders to 8, overlapping of scenes can be accomplished. For example, the recorder #1 can be recording the overlap portion of band #1 scene N-1, scene N and the overlap portion of scene N + 1; recorder #2 can be recording the overlap portion of scene N, scene N + 1 and the overlap portion of scene N + 2. In this manner, the output recorder will be recording alternate scenes with the proper overlap requirements. Since the HDDT thruput was based on two passes thru the TM data the option exists either to use the eight output recorders to record alternate images for all seven bands on each pass or to record all required image for bands 1 thru 4 on the first pass and bands 5 thru 7 on the second pass.

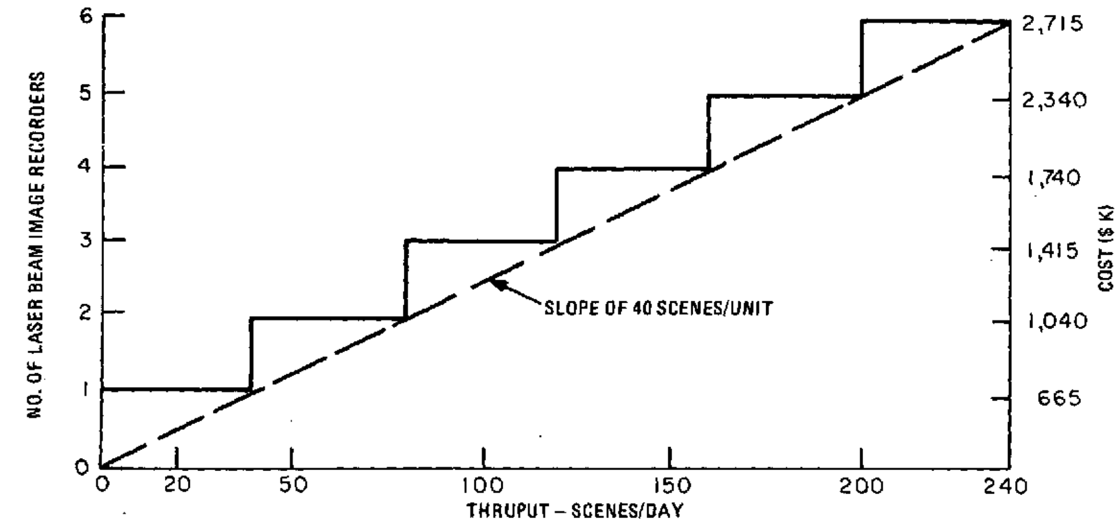
To satisfy the maximum system throughput requiring 200 scenes/day, the configuration could be expanded by increasing the number of output HDDT recorder units to 14 and increasing the processing unit to handle the 14 units at a total cost increase of approximately $175K.

Utilizing the 40 scenes/day throughput for the individual LBIR's, the number of LBIR's required and the costs for the Film Image Generation Subsystem as a function of throughput for the range of 20 to 200 scenes/day is plotted on Figure 4-36. Since the LBIR's are used to process the catalog film images also the system throughput has to be increased, as noted on this figure, to account for this processing load.

Comparison of Alternatives

To provide for the overlapping requirements, Alternative #1 requires multiple passes through the HDDT's to provide the overlap image data or stopping, rewinding and starting the HDDT's; both approaches will tend to decrease the operating efficiency of the LBIR's even further.

The disadvantage of Alternative #2 of not performing the film cataloging on-line is not considered a major factor since priority can be assigned that function in the off-line



CUSTOM SCENES/DAY	CATALOG SCENES/DAY	TOTAL THRUPUT SCENES/DAY
X	40 100 175 250	X + 5 X + 11 X + 20 X + 28

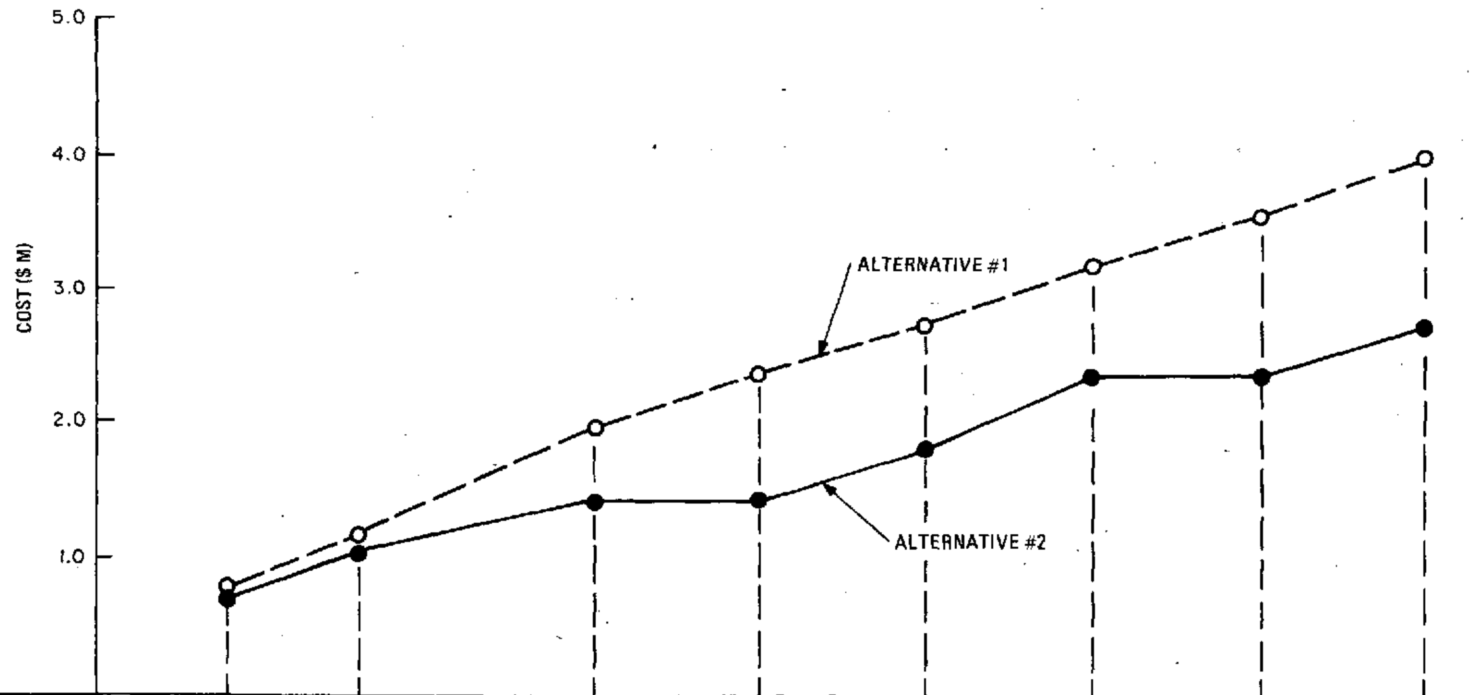
Figure 4-36. Throughput Vs. Number of Recorders and Cost (Alternate #2)

mode and should not delay the delivery of copies of the resampled HDDT's to the major users.

The major factor then, in comparing the alternatives, is cost. Figure 4-37 presents the cost comparison data at selected system throughput rates for the standard cataloging scenes/day (40 to 250 scenes/day) and custom scenes/day (20 to 200). At a low system throughput rate, the costs are approximately the same for both alternatives, but alternative #2 becomes the preferred approach as the system throughput is increased.

Impact of TM Oversampling

TM oversampling in the X direction, over the range from greater than 0% to 60%, has an impact on the Film Image Generation Subsystem.



CUSTOM OFF-LINE THRUPUT PLUS STANDARD ON-LINE THRUPUT		20 + 40	40 + 40	75 + 100	100 + 175	125 + 250	150 + 250	175 + 250	200 + 250
ALTERNATIVE #1	# OF LBIR's	2	3	5	6	7	8	9	10 (198)
	COST	$0.770 M	$1.175 M	$1.985 M	$2.390 M	$2.795 M	$3.200 M	$3.605 M	$4.010 M
ALTERNATIVE #2	# OF LBIR's	1	2	3	3	4	5	5 (170)	6
	COST	$0.665 M	$1.040 M	$1.415 M	$1.415 M	$1.790 M	$2.340 M	$2.340 M	$1.715 M
	DELTA COST	$0.105 M	$0.135 M	$0.570 M	$0.975 M	$1.005 M	$0.860 M	$1.265 M	$1.295 M

Figure 4-37. Cost Comparison of Alternatives #1 and #2

Impact on Laser Beam Image Recorder

In the generation of TM custom images with no oversampling, the video writing speed required was established at 14.8 pixels/μ second (see Table 4-30). The required video writing speed with 60% oversampling is 1.6 times 14.8 pixels/μ second or 23.7 pixels/μ second; since the baseline LBIR has the capability of 30 pixels/μ second this does not present any problem on the recording unit.

However the electronic unit associated with the LBIR would require modification to include the oversampling requirement. The TM custom images utilize an effective 30 micron pixel size by writing the same video information on three consecutive 10 micron spots in the width direction of the fast scan and three lines high. Oversampling of 50% in the X direction could be easily achieved by changing the video information every two consecutive 10 micron spots. It should also be possible to adjust the pixel width by multiplying up the pixel clock and changing the analog amplitude some fraction of the new clock cycle — for example, multiplying the pixel clock by 4 which gives 12 pixel clock intervals over the 30 micron and changing the analog amplitude at 8, 9, 10 or 11 clock intervals will provide for discrete oversampling values of 50%, 33-1/3%, 20% and approximately 9%. The LBIR electronic unit would have to be tailored to the exact oversampling employed by the TM sensor. Oversampling in the y direction can be done for 50% by writing the same video data on two lines instead of three, any other values would require major modification of the basic baseline LBIR with associated cost impacts.

With regards to the TM Catalog Image the effects of oversampling in the X direction would provide a distorted format if no corrections were made — for example, oversampling of 50% would result in an image size of 3.6 inches wide by 2.4 inches long for a corresponding area of 185Km x 185Km. The distorted image for Catalog Images was not considered acceptable. Changes to the LBIR, such as additional line rate(s) and changes to the electronics, to compensate for oversampling in this mode of operation, were not pursued on the basis of cost since this compensation could be performed in either the Digital Image Correction Subsystem or the HDDT Processing Subsystem at some fraction of the costs to modify the LBIR.

Impact on HDDT Preprocessing Subsystem

TM oversampling in the X direction effectively increases the data to be processed through the HDDT Preprocessing Subsystem and therefore reduces the throughput rate. At 60% oversampling the effective throughput is reduced from 165 scenes per day to 126 scenes/day. Utilizing the previous approach of increasing the number of output recorders will increase the throughput to 192 scenes/day which is slightly below the upper limit of the requirement range of 200 scenes/day. At 50% oversampling the corresponding figures are 132 scenes/day and greater than 200 scenes/day, respectively.

Extractive Processing and Browse Facility Design/Cost Tradeoffs

Requirements and Analysis

Functional Requirements

The functional requirements for the EOS Browse File and Extractive Processing Subsystem are as follows:

- Browse modes will be provided for
  - narrative description archive
  - B/W photo archive will hardcopy output, and
  - digital data archive from HDDT
- One to six browse terminals for each mode
- Digital data display terminals for viewing, training and classification of multi temporal/spectral data

- Provisions for utilization of User provided CCT/HDDT image data tape
- Provide for utilization of each terminal for 28 channel (i.e. 4 overflights) of image data
- Provide for hard copy thematic map output in both B/W and color
- Provide for training through classification interactive timeof 10 to 15 seconds, and
- Provide for bulk processing of EOS 28 channel temporal frame in approximately two minutes

Processing Flow Diagram

The process flow diagram for the EOS Browse File and Extractive Processing is shown on Figure 4-38.

Discussion and Tradeoffs

Archival Query and Film Retrieval

The archival query subsystem could work with: (1) an on-line computer based data base; (2) computer listing document; or (3) combination of the first two. Computer listing documents would be the lowest in cost but would have less flexibility. A total on-line system with interactive terminal and hard copy printout would be the most flexible, easily updated, and expensive. However, the cost per terminal would be relatively small (see Table 4-31) and if the total number is small (i.e., 6) this approach would be the most desirable. This is the approach assumed for this study. The software cost for maintaining and updating the archival retrieval data is included under the information management system.

For the film retrieval and browse subsystem the major requirements were to minimize film handling and to display high-quality B/W second-generation film to the user. The

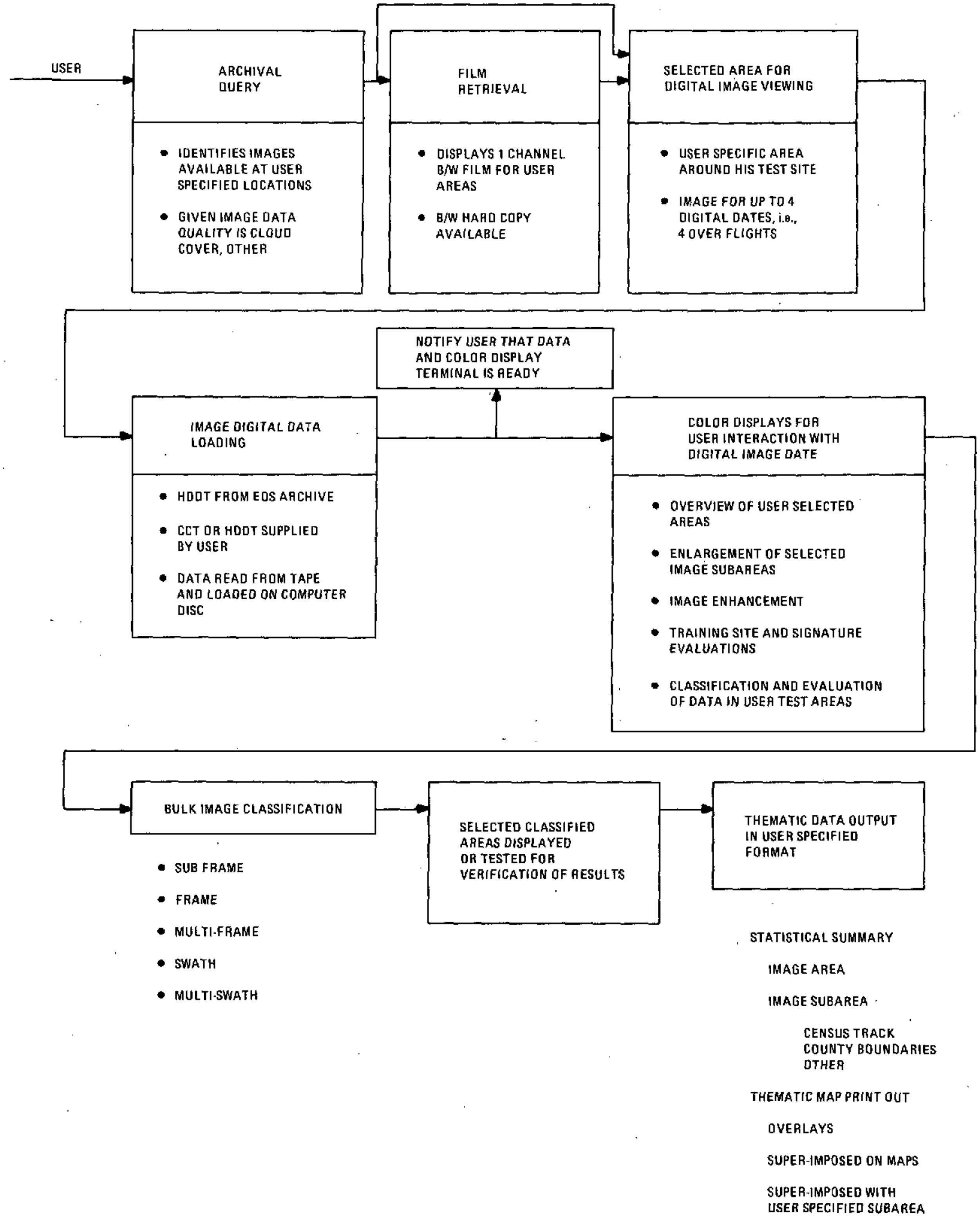


Figure 4-38. Processing Flow Diagram for EOS Browse File for Extractive Processing

TABLE 4-31. SUMMARY OF BROWSE FILE AND EXTRACTION PROCESSING SUBSYSTEM COSTS

Cost Item \ Configuration and Comments	One User Stations	Three User Stations	Six User Stations	Comments
o System Design/Integration	4 Man Years	5 Man Years	5.5 Man Years	
o Hardware				
a) HDDT	1@ $42K	2@ $84K	2@ $84K	Lockeed 40 mb/s HDDT (Most cost effective HDDT)
b) CCT	1@ $61K	1@ $61K	2@ $92K	CDC/IBM 1600/6250 CCT (200 ips)
c) Computer System	$180K	$210K	$250K	PDP 1145 plus 64 to 128K core
d) Image Storage Disc and Controller	$60K	$170K	$320K	DDC A7310 or DDC 9100/station (100 m bit storage and 16 to 18 mb/s transfer rate)
e) Interactive Display Station	$50K	$150K	$300K	600 x 480 pixels x 16 bit plane memory/station
f) Hard Copy				
- Gould	$15K	2@ $30K	3@ $45K	Gould 2000 line ptr
- Color Printer	$50K	$50K	2@ $100K	Dicomed Model 47 Color Printer
g) Special Processor	$180K	$200K	$250K	200-300 K Pixels per scene processing
h) Archival Query and Film Retrieval Display and Hard Copy	3@ $80K	3@ $80K	6@ $160K	Textronic Terminal with hard copy. Optical viewer roll film display with hard copy.
Total	$718K	$1,080K	$1,601K	
o Software	5 Man Years	6 Man Years	6.5 Man Years	
o System Checkout	2 Man Years	3 Man Years	3.5 Man Years	
Total Cost	$0.7M + 11 Man Years	$1.1M + 14 Man Years	$1.6M + 15.5 Man Years	
o System Operation and Maintenance Support	1 Eng 1 Tech	1 Eng 1 Tech	1 Eng 2 Tech	

two approaches which best seem to meet these requirements were catalog of individual photo or uncut rolls of photos. Though the first approach offers the most flexibility, the storage requirements for a catalog of individual photos were considered to be too large when compared to the uncut roll film. Therefore for this study, film retrieval and browse subsystem will consist of rolls of second-generation B/W photo which can be inserted and displayed on optical viewers. Hard copy can be obtained by microfinch type prints or by polaroid film cameras. The cost of optical viewer/hard copy stations are also shown in Table 4-31.

Digital Image Browse and Extractive Processing

The interactive data terminal used for archival query will also be used to select the area for digital image viewing. The digital image data is retrieved from the EOS HDDT tape or can be provided by the user in either HDDT or CCT formats. The retrieval of the HDDT from the EOS tape archival could take from an hour to days and therefore a temporary tape archive will be maintained in the extractive processing facility. This archive will contain previously requested EOS or other user tapes. The user is notified by phone when the data he has requested will be loaded and when a terminal will be available.

The color image display console, computer, special processor, and image storage disc constitute the basic image browse/analysis subsystem (see Figure 4-39). Each color display can present a 600 x 480 color image and up to 32 themes, each theme having a different color. The display can be refreshed by either an analog video disc, a digital video disc, a solid-state memory, or a combination of the first three. The video disc offers the most storage and the solid-state memory the least storage for a given cost. However, the solid-state memory is more reliable and can be loaded faster. For this study a 16-bit plane 600 x 480 solid-state memory was assumed for refresh. However, for the cost given, either of the two disc approaches could also be used.

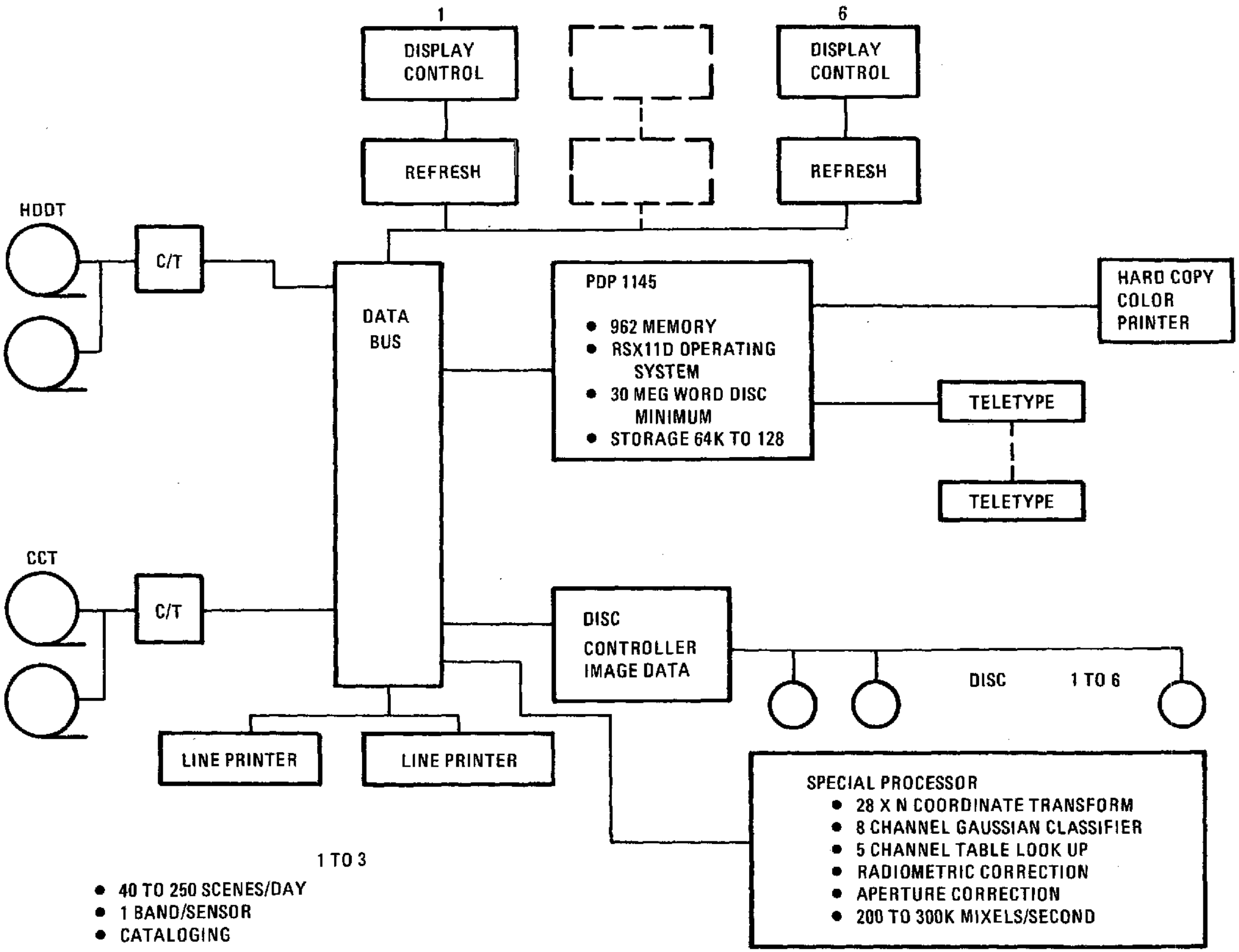


Figure 4-39. EOS Extractive System Hardware Diagram

The computer use was assumed to be the PDP 1145 but other computer systems with approximately the same performance could be used and the hardware cost would be approximately the same. The biggest advantage of the PDP-1145 is that it is being used in several existing processing systems and hence a considerable amount of software is and will be developed and in addition a large number of peripherals are available.

The image storage disc will store approximately 1000 x 1000 pixels for up to 28 channels (i.e., 4 EOS over flights). While all of the data will be available for processing only three channels will be displayed at a time if the solid-state memory is used for the refresh display. However, different channels can be loaded and displayed in less than 10 seconds.

Once the user has inspected, trained and classified the image data on the disc, he can then request a bulk classification of data from the HDDT or CCT in the temporary archive. After bulk classification selected classified area can be displayed and/or tested to verify the classification results. The results can be printed as statistical summary data or as a theme map with overlap for various image subareas predefined by the user. Hard copy will include photo of the display, line printer listing, and color hard copy. Several color hard copy printers are presently available for under $50K and by 1976 the selection will probably be even larger. For this study the color hard copy device was assumed to be the Dicomed Model 47.

Table 4-31 summarizes the system cost for three different configurations consisting of one, three, and six display consoles. The cost per terminal is much more attractive for a large number of terminals because the computer and special processing hardware can be time shared thus reducing the per-terminal cost.

4.4 LOW COST READOUT STATION DESIGN CONCEPT AND DESIGN/COST TRADEOFFS

4.4.1 PURPOSE AND SUMMARY

The purpose of the study was to generate cost/performance parametric data for the Low Cost Readout Station (LCRS) such that:

- The cost for a minimum station (one that provides only radiometrically corrected data on a computer compatible tape) could be established as a function of received data rate (throughput).
- The costs could be established as a function of data correction capability (product quality) up to and including full radiometric and geometric corrections, and
- The costs of performing the data correction at the Low Cost Readout Station(s) could be provided for higher level system tradeoffs involving ground vs. on-board data correction considerations.

The key results of the study are as follows:

- The cost of the data acquisition subsystem (from antenna to high density digital tape recorder) is a function of data rate with the high density digital tape recorder and bit synchronizer being the influencing items.
- The cost of the data processing and correction subsystem is essentially independent of data rate but primarily dependent on the degree of correction capability.
- Radiometric correction functions performed on the ground is most cost effective approach; geometric correction functions performed on-board the spacecraft appears as the viable approach based on cost delta of $35K/station and the one time non-recurring, but significantly high cost of software.

- The non-recurring costs of the minimum Low Cost Readout Station as a function of data rate and associated data information content are as follows:

Data Rate Mb/s	Data Information Content	Costs * $ Thousands
3.75	3 bands of TM @ 90 meter resolution @ 100% swath width	166
7.5	3 bands of TM @ 60 meter resolution @ 100% swath width	171
15.0	3 bands of TM @ 30 meter resolution @ 50% swath width	185
22.5	3 bands of TM @ 30 meter resolution @ 75% swath width	200
30.0	3 bands of TM @ 30 meter resolution @ 100% swath width	220

*Costs do not include faulty preparation, installation, checkout and operation of the basic LCRS as well as the unique local user display and extractive processing subsystem.

4.4.2 REQUIREMENTS

The results of GE's Total Earth Resources System for the Shuttle Era (TERSSE) Study showed that the range of requirements are so broad that no single set can be established to "typify" the user stations. Therefore, the study was performed and the results presented parametrically. The requirements, requirement ranges and alternatives utilized in this study are presented in Table 4-32.

In addition, while the data acquisition and data processing and correction portions of the Low Cost Ground Readout Stations can be standardized to achieve commonality and hence lowest costs, the display and extractive portion of the stations must generally be tailored to fit the needs of the particular user and therefore, for all practical purposes, station unique.

TABLE 4-32. LOW COST GROUND READOUT STATION REQUIREMENTS

Parameter	Reference Baseline	Range	Alternative
Instrument Type	TM - Te-Gulton HRPI - Te-Gulton		Other TM instruments Other HRPI instruments
Coverage Area	185 km x 185 km	up to 555 km x 555 km	
Data Rate	15 Mb/s	3.75 Mb/s to 30 Mb/s with breakpoints @ 3.75, 7.5, 15.0, 22.5 and 30 Mb/s	
Resolution*		TM - 30, 60 & 90 m HRPI - 10 m	
Number of Bands*		TM - 3 to 4 of 6 plus 7 HRPI - 1 to 4	
Swath Width*		TM - 25 to 100% of full swath HRPI - 33 to 100% of full swath	
Correction Capability	o Radiometric correction on ground o Data reformatting and geometric correction on vehicle		No correction to full geometric correction on the ground

*Resolution, number of bands and swath width to be consistent with data rates.

4.4.3 SYSTEM DESIGN

The Low Cost Readout Station is comprised of three major subsystems — a data acquisition subsystem, a data processing and correction subsystem and display and extractive processing subsystem. A block diagram of the Low Cost Readout Station is shown on Figure 4-40.

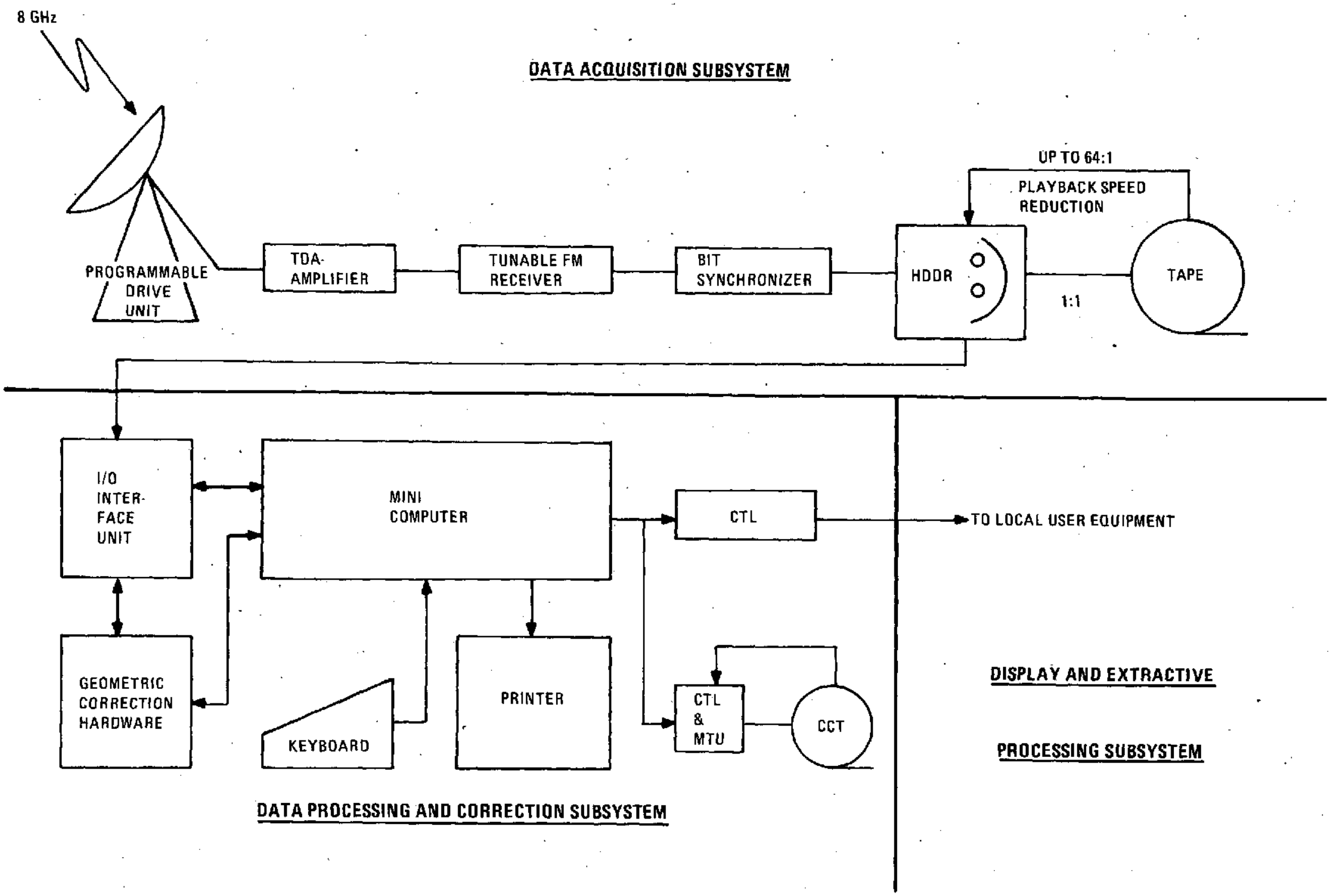


Figure 4-40. Low Cost Ground Readout Station Block Diagram

The functional requirement for the data acquisition subsystem is to acquire and receive the modulated 8 GHz spacecraft signal and to demodulate and record the video data. Upon completion of the spacecraft pass (30 seconds to 120 seconds) over the local user station, the recorded data is played back at a reduced speed into the data processing and correction subsystem.

The major components of the data acquisition subsystem consist of a small receiving antenna, preamplifier, tunable FM receiver, bit synchronizer and a high density digital tape recorder with the capability of tape speed reduction ratios in the order of 64:1.

The functional requirements for the data processing and correction subsystem are to digitally correct the data received from the high density digital tape in the playback mode (at a rate of one band per pass) and record the data on a magnetic tape unit device. The degree of correction to be considered is from no correction (data reformatting only) to full radiometric and geometric correction. The digitally corrected computer compatible tape is then output at a reduced speed compatible with the display and/or film devices contained in the display and extractive processing subsystems.

The major components of the data processing and correction subsystem is a minicomputer with a keyboard/printer, special purpose hardware for geometric correction, an I/O interface (for interfacing between the high density digital tape recorder of the data acquisition system and the computer and special purpose hardware), a magnetic tape unit and a buffer/controller unit to interface with the display and extractive processing subsystem.

The functional requirements for the local user display and extractive processing subsystem, for all practical purposes, will be station unique. The interface between this subsystem and the data processing and correction subsystem is the corrected computer compatible tape through the buffer/controller unit.

4.4.4 DESIGN/COST TRADEOFFS

Data Acquisition Subsystem

The antenna size, antenna tracking method, and preamplifier are the key design/cost tradeoff items within this subsystem; the receiver is a low cost item and has no significant alternatives except tunable vs. fixed tunned; the bit synchronizer and the high density digital tape recorders are not tradeoff items but their costs are related to system data rate.

Various ground antennas were considered. A fixed antenna would not be practical unless the EIRP of the spacecraft was increased by about 25 dB which is not considered practical nor desirable. A fan beam antenna may be feasible but substantial engineering development would be required and not practical under the low cost restrictions. Therefore an existing off-the-shelf circular antenna with some form of tracking is the preferred approach.

Three types of antenna tracking methods were considered. Table 4-33 provides a summary of antenna costs for 75 cm and 1.8 meter reflectors with various tracking methods.

TABLE 4-33. ANTENNA COSTS VS. TRACKING METHODS

Tracking Method	75 CM Reflector	1.8 Meter Reflector
Auto track (pseudo-monopulse)	$ 74K	$ 90K
Programmed Track (paper tape drive input)	$ 46K	$ 75K
Manual Track	$ 41K	$ 51K

The auto track antenna can be eliminated because of costs. The programmed track antenna, using punch paper tape input is higher in cost than the manual tracking antenna \$ 46K vs. 41K. Manual antenna pointing control would be improved utilizing the 75 cm reflector rather than the 1.8 meter reflector on the basis of wider beam width (3.3° vs. 1.4°).

The selection of the antenna size is dependent on the preamplifier utilized. Table 4-34 identifies the minimum antenna size required as a function of preamplifier type and also includes typical prices for the preamplifiers.

TABLE 4-34. MINIMUM ANTENNA SIZE VS. PREAMPLIFIER TYPE

Preamplifier Type	Typical Costs	Minimum Antenna Diameter
Uncooled Paramp	\$ 7.6K	67 cm
GAS-FET	4.5K	115 cm
TDA	1.3K	120 cm
Mixer	~ 1.0	140 cm

Cooled paramps were not considered because of their high cost.

Based on the antenna and preamplifier information presented in Tables 4-33 and 4-34, the most cost effective antenna/preamplifier would be the 75 cm reflector with manual tracking and uncooled paramp. The \$5 thousand cost delta to improve to programmed track antenna appears to be justified to minimize operator interaction during a pass. The additional recurring cost to add the capability to the data processing and correction system is minimum (~2.0K); the software cost for generating the antenna tracking profile and converting it to punch paper tape is considered small and a one time non-recurring cost.

The conclusion, therefore, is to use the 75 cm reflector with the programmed track method and an uncooled paramp.

The effect of increasing the area coverage from a 185 km by 185 km area (equivalent to 1 scene) to 555 km by 555 km area (equivalent to 9 scenes) is not significant in terms of costs and can be accommodated by the antenna/preamplifier configuration defined above.

The cost of the receiver for this application has been quoted at $7K for a fixed bandwidth.

The costs of bit synchronizer production units for this application have been quoted at $6.6K for 8 Mb/s, $10.6K for 15 Mb/s and estimated at $20K and $30K for 22.5 Mb/s and 30.0 Mb/s respectively. Some development costs for the initial unit are required - $10 to 15K for the 8 Mb/s and 15 Mb/s units and $30 and 45K for the 22.5 Mb/s and 30 Mb/s units.

The high density digital tape recorder varies in cost from $50K for use at 3.75 Mb/s to $80K at 30 Mb/s.

The miscellaneous costs associated with a cabinet to house the paramplifier, receiver bit synchronizer, and power supplies, etc., is estimated at $2.5K.

Table 4-35 summarizes the recurring costs of the Data Acquisition Subsystem for the Low Cost Readout Station. It does not however, include any facility preparation costs or installation and checkout costs since these will vary with the user station location.

<u>Data Processing and Correction Subsystem</u>

A functional block diagram of the low cost readout station data processing and correction subsystem is shown in Figure 4-41. The same high density digital tape recorder used to record the scene data from the spacecraft will be used at a speed reduction ratio up to 64:1 to reduce the required processing rate. This is made possible because the

TABLE 4-35. DATA ACQUISITION SUBSYSTEM COSTS AS A FUNCTION OF DATA RATE

Equipment \ Data Rates	3.75 Mb/s	7.5 Mb/s	15.0 Mb/s	22.5 Mb/s	30 Mb/s
• 75 cm Antenna with Programmed Track Method	46.0	46.0	46.0	46.0	46.0
• Uncooled Paramp	7.6	7.6	7.6	7.6	7.6
• Receiver	7.0	7.0	7.0	7.0	7.0
• Bit Synchronizer	6.6	6.6	10.6	20.0	30.0
• High Density Digital Tape Recorders	50.0	55.0	65.0	70.0	80.0
• Miscellaneous Equipment	2.5	2.5	2.5	2.5	2.5
• Subsystem Assembly and Test Cost*	5.0	5.0	5.0	6.0	7.5
Total Recurring Costs**	124.7	129.7	143.7	159.1	180.6

*Assumes that HDDT recorder will be checked out as part of Data Processing and Correction Subsystem.

**Does not include facility preparation cost or installation, checkout or operation costs, also based on minimum of ten units.

total throughput of the typical low cost readout station is very low. The format of the video data input to the synchronization/interface module is determined by the on-board data compactor. The data is synchronous and in a band-to-band registered annotated, spectrally interleaved, scan line sequential, PCM format.

Reformatting functions and geometric correction along the scan line will be performed on the spacecraft. The fact that it is scan line sequential, band-to-band registered and spectially interleaved completely eliminates the need for a reformatting function to be performed on the ground. The synchronous PCM data format considerably reduces the cost of the sync/demux special hardware. The performance of either radiometric or geometric correction on the ground requires an interface with the minicomputer.

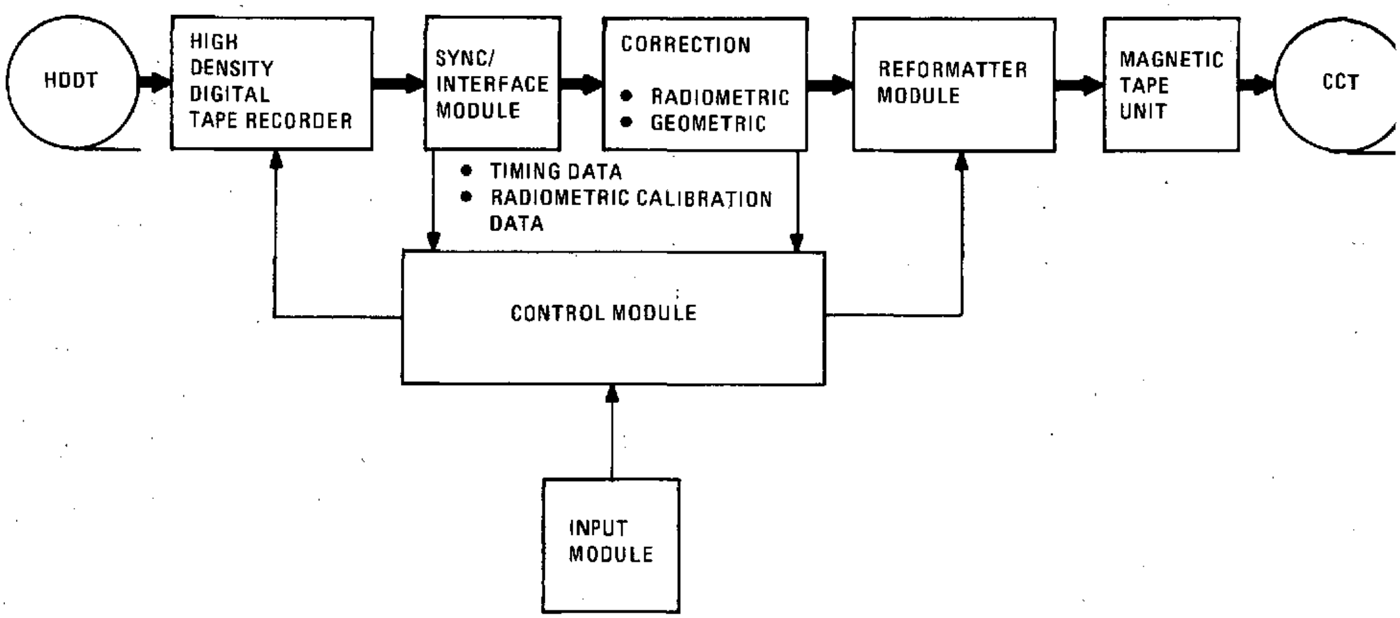


Figure 4-41. Data Processing and Correction Subsystem Block Diagram

The function of the computer may only be to ascertain the correct coefficient or to perform the correction based upon some calibration data in the video. The functional flow diagram is shown in Figure 4-42. The particular hardware implementation costed is dependent on the data header information and format. The following header information is assumed:

- Number of bands
- Band indicators
- Line length
- Resolution
- Sensor type
- Annotation (Latitude/Longitude) and
- Auxillary correction data
    - time
    - predicted ephemeris
    - sun calibration data
    - calibration lamp data
    - alignment biases
    - attitude rate and position

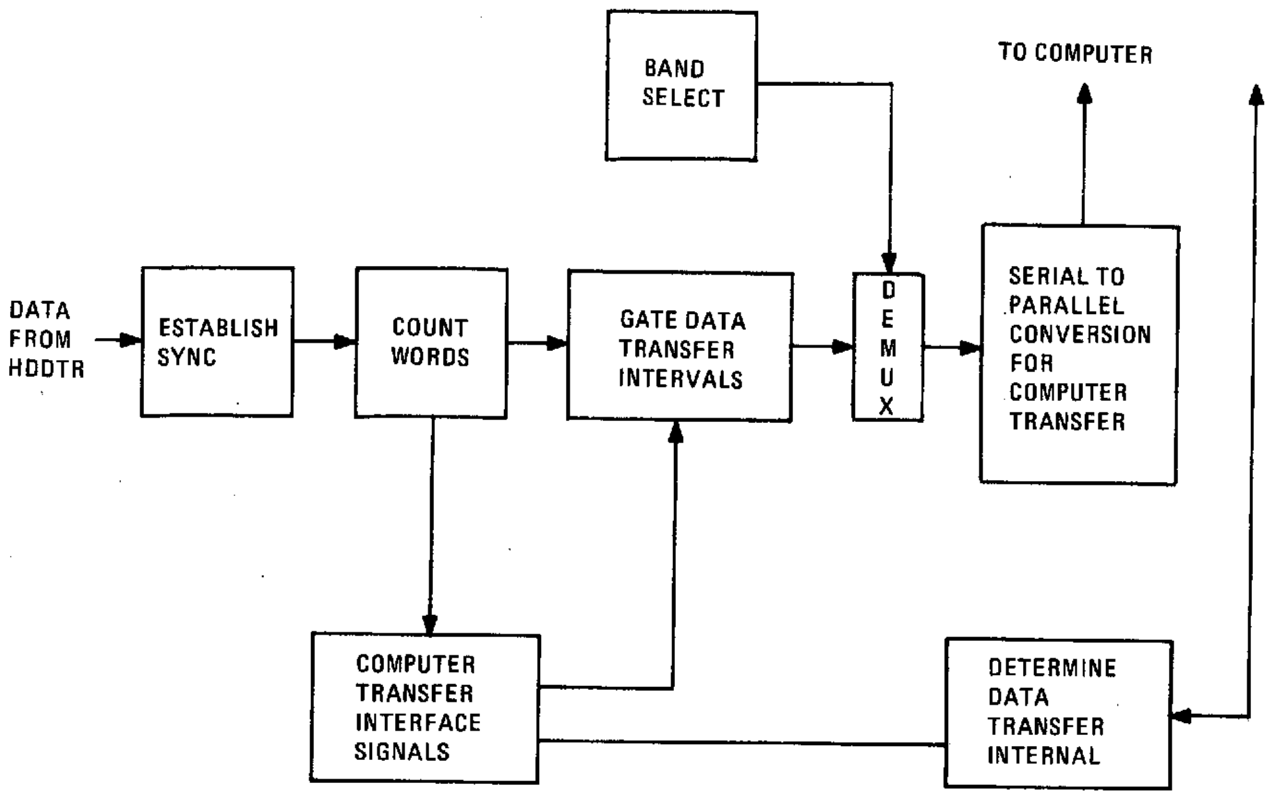


Figure 4-42. Sync/Demux Module Functional Flow Diagram

For the condition of no corrections, only a basic system consisting of a mini-computer (with 8K memory) with standard peripherals (keyboard and printer), an input/output interface unit and a magnetic tape unit with controller is required. For the condition of radiometric corrections an additional 4K of computer memory is required. The mini-computer is used to reformat the data, perform the table lookup correction and write the CCT. The 25 second swath of 7.5 megabit data/band can be written on a single 800 Bpi CCT in one pass. If the data rate exceeds 7.5 megabits/band the system configuration must include the addition of special hardware which is required to segment this data and multiple passes are required to remain below the acceptable CCT writing speed. The additional cost of this hardware is approximately $7K.

For the condition where geometric correction must be performed on the ground (not baseline), the minicomputer will not handle the computational load required to perform the correction and manipulate the pixels. Therefore, a special hardware processor has been used to implement the correction. The recurring cost of this special hardware was estimated to be approximately $30K; an additional $4K block of memory for the mini computer was also included in the cost to support the special processor.

The impact on the Low Cost Readout Station due to the various Thematic Mapper instrument candidates is approximately the same because of the reformatting and corrections performed on-board the spacecraft.

The different HRPI candidates do have a rather significant impact on the radiometric correction cost and complexity. The array HRPI's, because of the significantly larger number of detectors requiring radiometric corrections, introduce an increase of about $15K over the line scanners.

For both the TM and HRPI conical scanner, it is assumed that the data remains in the conical format and will be accounted for in the display and extractive processing subsystem.

Table 4-36 is a summary of the costs for the Data Processing and Correction Subsystem as a function of the various levels of ground corrections (data rates of $\leq$7.5 Mb/s per band were assumed in the cost presentation).

A significant conclusion can be drawn from the table, i.e., radiometric correction on the ground introduces a recurring cost of only $25K (the cost of 4K block of mini-computer memory). Therefore, radiometric correction on the ground is the preferred approach as opposed to correction on the spacecraft. On the otherhand full geometric correction on the ground introduces a recurring cost delta of $34K for each station. By performing radiometric correction on-board the spacecraft, a significant portion of the overall cost of the LCRS can be saved.

TABLE 4-36. DATA PROCESSING AND CORRECTION SUBSYSTEM CORRECTION CAPABILITY VS. COST (RECURRING)

Equipment	No Correction	Radiometric	Radiometric + Earth Rotation & Annotation	Radiometric + Earth Rotation & Annotation + Earth Curvature	Radiometric + Earth Rota. & Annotation + Earth Curv. + Resampling
Basic System • I/O Unit ($12.0K) • Computer ($13.0K) • Mag. Taped Controller ($7.5K)	$32.5K	$32.5K	$32.5K	$32.5K	$32.5K
Computer Memory Addition	0.0	2.5K (8K ⟶ 12K)	5.0K (8K ⟶ 16K)	5.0K (8K ⟶ 16K)	5.0K (8K ⟶ 16K)
Special Purpose Hardware	0.0	0.0	0.0	30.0K	30.0K
Subsystem Assembly and Test	6.0	6.0K	6.5	8.0K	8.0K
Total Recurring Cost	$38.5K	$41.0K	$44.0K	$75.5K	$75.5K

4.4.5 PERFORMANCE/COST CAPABILITY

Table 4-37 provides a summary of the Thematic Mapper and HRPI data information options as a function of data rates.

For those data information options identified in Table 4-37 which have swath widths of less than 100%, on-board storage is required to buffer that portion of the swath and clock it out to the ground at the reduced rate (for example, a Thematic Mapper band which has a data rate of approximately 10 Mb/s and has a swath width reduction of 25% will have a data rate of 2.5 Mb/s).

The significant points on this table are as follows:

- 100% swath width for 3 bands and 90 meter resolution for the Thematic Mapper instrument can be satisfied with a low data rate of 3.75 Mb/s

TABLE 4-37. TM AND HRPI DATA INFORMATION OPTIONS
AS A FUNCTION OF DATA RATE

		Data Rates						
Thematic Mapper*		3.75 Mb/s	7.5 Mb/s	15.0 Mb/s	22.5 Mb/s		30.0 Mb/s	
30 Meter Resolution	Band	X	3	3	3	4	3	4
	Swath Width		25%	50%	75%	50%	100%	75%
60 Meter Resolution	Band	3	3	4				
				- -	- - - - - - - -		- - - - - - - →	
	Swath Width	50%	100%	100%				
90 Meter Resolution	Band	3	4					
				- - - - - -	- - - - - - -		- - - - - - - →	
	Swath Width	100%	100%					
HRPI 10 Meter Resolution								
1 Band	Swath Width	X	33%	67%	100% - -		- - - - - - - →	
2 Bands	Swath Width	X	X	33%	50%		67%	
3 Bands	Swath Width	X	X	X	33%		44%	
4 Bands	Swath Width	X	X	X	X		33%	

*To account for the addition of Band 7, increase the data rates by about 0.6 Mb/s.

- 100% swath width for 3 bands and 60 meter resolution for the Thematic Mapper instrument can be satisfied with a data rate of 7.5 Mb/s

- 50% swath width for 3 bands and 30 meter resolution for the Thematic Mapper instrument can be satisfied with a data rate of 15 Mb/s; 30 Mb/s is required for 100% swath width.

- 100% swath width for 1 band and 10 meter resolution for the HRPI instrument requires 22.5 Mb/s; 3 bands at 33% swath width also requires 22.5 Mb/s

The recurring costs for the Low Cost Readout Station (excluding facility preparation, installation, checkout and operations and the Display and Extractive Processing Subsystem) is presented on Figure 4-43 as a function of data rate.

Conclusions to be shown from this figure are as follows:

- The cost of the Data Acquisition Subsystem is a function of data rate varying from $125K @ 3.75 Mb/s to $181K @ 30.0 Mb/s.

- The cost of the Data Processing and Correction Subsystem is essentially independent of data rate over the range considered but largely dependent on the degree of ground correction implemented.

- The negative delta cost of $2.5K for removing the radiometric correction function on the ground is small and this function should remain on the ground.

- The positive delta cost of $35K for performing the geometric correction on the ground is of sufficient magnitude that the costs of performing this function on-board should be evaluated considering the potentially large number of Low Cost Readout Stations.

- The recurring cost of the baseline system at the selected benchmarks are:

$166K	@	3.75 Mb/s
$171K	@	7.5 Mb/s
$185K	@	15.0 Mb/s
$200K	@	22.5 Mb/s
$220K	@	30.0 Mb/s

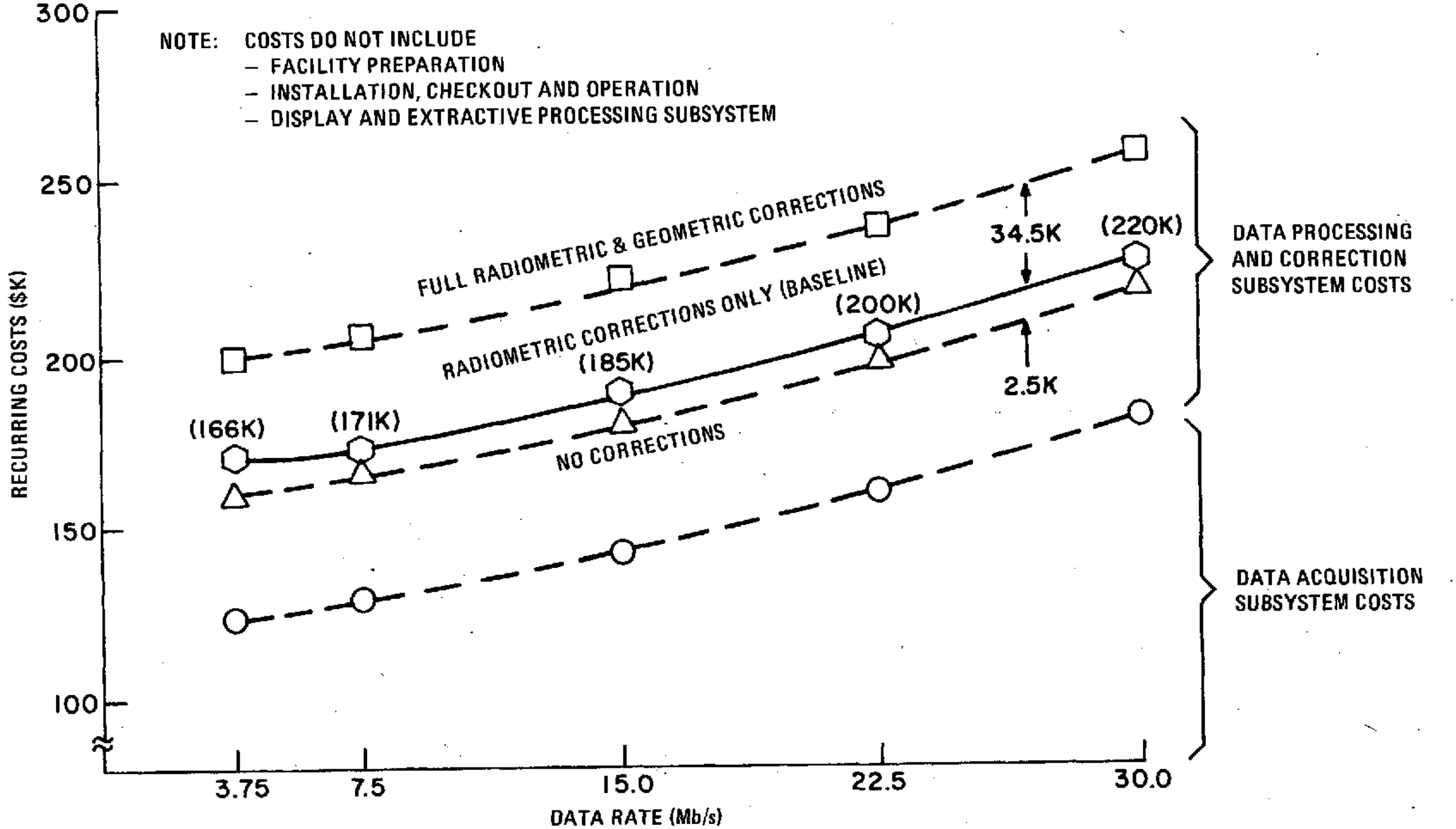


Figure 4-43. Recurring Costs for Low-Cost Ground Readout Station as a Function of Data Rate and Correction Capability

SECTION 5

PROGRAM COST SUMMARY

The following sections present cost summaries for three EOS spacecraft:

Designation	Payload
EOS-A	1 MSS & 1 TM
EOS-A'	1 MSS
EOS-A"	2 MSS & 1 TM

EOS-A and A' are now considered to be the first two EOS missions with an operational rather than R&D mission emphasis. The 5-Band MSS is the operational instrument while the Thematic Mapper is a piggy-back R&D instrument. EOS-A" has been costed to aid in resolving the question of whether or not the operational system should be composed of one larger or two smaller satellites. Approximately nine day coverage is required which could be accomplished with two relatively simple spacecraft each carrying a single MSS or with a single spacecraft carrying two instruments to a slightly different mission altitude. In the first case, spacecraft would be launched at one-year intervals with a two-year operating life. Each would be in 18-day repeat orbits. Two spacecraft provide 9-day coverage. In the second case, spacecraft are launched every two years with a two-year operating life. The two instruments and mission altitude provide 9-day coverage.

The cost data is predicated upon the implementation of the Low Cost Management Approaches described in Report 4 of the EOS Systems Definition Study. In particular, the test approach outlined in this report is assumed in the cost presented in this section.

Other assumptions under which the costs were developed are as follows:

- o Purchases of common hardware are to be made in minimum lots of five in order to take advantage of the cost savings in multiple buys.
- o Minimum redundancy has been employed in the design of the spacecraft subsystems.

- The spacecraft and modules do not include hardware for shuttle on-orbit serviceability, but a modular design which can include these features in the future has been assumed.
- Costs for global coverage using WBVTR's are included. TDRS capability costs are not included. (They are presented in a separate section.)
- Power module and array for basic spacecraft sized to deliver 200 W orbit average to payload (in addition to basic spacecraft demands).
- X-band is used for all wideband communications to the ground.
- The central data processing facility will handle up to 175 scenes/day per sensor of a Thematic Mapper/HRPI payload.
- Only the design and developed cost of the Low Cost Ground Station is included. Recurring costs are estimated for a single unit assuming it to be one of ten produced.
- Spacecraft are to be launched using the Delta 2910 or 3910.
- Launch dates for EOS-A and EOS-A' are early 1979 and 1980 respectively.
- 1974 costs are presented - There has been no attempt to postulate the effects of inflation over the EOS mission model time span. Costs are presented through G&A; they do not reflect a contractor's fee.

5.1 CONCLUSIONS

As a result of the cost trades and analysis conducted during the EOS System definition study the following conclusions can be reached.

- A low cost basic spacecraft can be produced for a recurring cost of about 7-Million Dollars.
- The Ground Data Handling System for the EOS mission that includes a TM & HRPI costs about 20 Million assuming processing of about 175 scenes/day.
- A Low Cost Ground Station to receive data at a rate of 15 Mbps can be produced for a recurring cost of about 200K. Costs will vary somewhat with corrections performed.

o A single spacecraft (A") carrying two MSS's and 1 TM is more economical than a two spacecraft system (A and A') by 17 Million dollars.

Cost summaries from which the above conclusions were derived are shown in the sections following.

5.2 SPACECRAFT COST SUMMARIES

Tables 5.1, 5.2, and 5.3 present the spacecraft costs for EOS-A, EOS-A', and EOS-A". In each case the costs of the basic spacecraft are separated from the costs of mission peculiar items and both non-recurring and recurring columns are shown. The basic bus cost is for an integrated, tested spacecraft less all mission peculiars. A brief definition of each subsystem and system level task is shown in Table 5.4.

5.3 GROUND DATA HANDLING SYSTEM COST SUMMARIES

Table 5.5 shows the non-recurring and recurring costs for the Ground Data Handling System required to support the EOS spacecraft and to process the instrument data for dissemination to the users. Costs are shown for the OCC, the Central Data Processing Facility with a separate line item for annual operations costs. Network modifications and the Low Cost Ground Station costs are also included.

The costs include all hardware required, program management, system engineering, spares, system integration and test, reliability, quality assurance, documentation, operations support, support services, user services, secretarial support and travel and living.

5.4 MISSION COST SUMMARY

The EOS-A, A', and A" mission cost summaries are shown in Table 5-6. The launch vehicles used in this cost summary are the Delta 2910 and 3910 and the spacecraft have been designed weightwise with this capability in mind. Table 5.6 also shows the recurring cost differences between the one spacecraft mission vs. two spacecraft. The significant message is that the operational mission is most cost effective if a single spacecraft is

Table 5.1. Spacecraft A Cost Summary
(Dollars x 1000)

	Basic	S/C	Mission	Peculiar	EOS-A P/L: 1MSS/1 TM
Subsystem Level	NR	R	NR	R	Remarks
Attitude Control System Module	5300	1400	-	-	
Power Module + Solar Array	3200	1200	-	-	
Communications & Data Handling Mod.	5500	1350	300	-	
Structure	100	50	220	100	
Thermal Control	-	-	-	-	Included in each module or S/S
Electrical Distribution	300	100	-	-	Harness included in each mod or S/S
Interstage Adapter	-	-	150	50	
Propulsion Module	400	270	630	180	No retrieval capability
Wideband Module	-	-	5700	2900	Includes WB Gimbal, HDMR
Thematic Mapper Module	-	-	(12000)	(6000)	GFE
MSS Module	-	-	(2000)	(5000)	GFE
DCS	-	-	20	200	
Mechanisms	-	-	-	-	
Systems Level					
Program Management	1700	600	2100	1000	
Systems Engineering	3000	140	4000	300	
Pre-S/C Integration Test (BIT)	250	-	400	-	
System Integration (P/L)	-	-	600	100	Payload only.
S/C Integration & Assy.	800	200	1200	300	
S/C System Test	2000	700	-	800	Includes SITE
Systems Test Equipment	1800	600	1500	800	
Reliability	400	-	700	-	
Quality Assurance	900	210	1200	500	
Documentation	220	100	500	250	
Launch Operations	200	-	500	300	
Sec. Services & T&L	700	200	170	900	
TOTALS	27270	7120	21320	8680	64,390
			(14000)	(11000)	GFE

Table 5.2. Spacecraft A' Cost Summary
(Dollars X1000)

Subsystem Level	Basic NR	S/C R	Mission NR	Peculiar R	EOS-A' P/L: MSS Remarks
Attitude Control System Module		1400		-	
Power Module + Solar Array		1200		-	
Communications & Data Handling Mod.		1350		-	
Structure		50		100	
Thermal Control		-		-	Included in each module or S/S
Electrical Distribution		100		-	Harness included in each Mod or S/S
Interstage Adapter		-		50	
Propulsion Module		270		180	No retrieval capability
Wideband Module		-		2900	Includes WB GIMBAL, HDMR
Thematic Mapper Module		-			
MSS Module		-		(5000)	GFE
DCS		-		200	
Mechanisms		-		-	Included in each module or S/S
Systems Level					
Program Management		600		1000	
Systems Engineering		140		300	
Pre-S/C Integration Test (BIT)		-		-	
System Integration (P/L)		-		300	Payload only
S/C Integration & Assy.		200		300	
S/C System Test		700		800	NOTE:
Systems Test Equipment		600		800	Non-recurring costs for
Reliability		-		-	EOS-A' are included in EOS-A
Quality Assurance		210		450	estimates.
Documentation		100		200	
Launch Operations		-		250	
Sec. Services & T&L		200		800	
TOTALS		7120		8630	15,750
				(5000)	GFE

Table 5.3. Spacecraft A" Cost Summary
(Dollars 1000)

Subsystem Level	Basic S/C NR	Basic S/C R	Mission Peculiar NR	Mission Peculiar R	EOS-A" P/L: 2 MSS/ 1 TM Remarks
Attitude Control System Module	5300	1400	-	-	
Power Module + Solar Array	3200	1200	-	-	
Communications & Data Handling Mod.	5500	1350	300	-	
Structure	100	50	230	110	
Thermal Control	-	-	-	-	Included in each module or S/S
Electrical Distribution	300	100	-	-	Harness included in each Mod or S/S
Interstage Adapter	-	-	150	50	
Propulsion Module	400	270	630	180	No retrieval capability
Wideband Module	-	-	5700	3450	2 MSS / 1 TM
Thematic Mapper Module	-	-	(12000)	(6000)	(GFE)
MSS Module	-	-	(2000)	(10000)	2 MSS Modules (GFE)
DCS	-	-	20	200	
Mechanisms	-	-	-	-	Included in each module or S/S
Systems Level					
Program Management	1700	600	2100	1050	
Systems Engineering	3000	140	4200	320	
Pre-S/C Integration Test (BIT)	250	-	420	-	
System Integration (P/L)	-	-	630	100	P/L Only
S/C Integration & Assy.	800	200	1260	310	
S/C System Test	2000	700	-	840	Includes SITE
Systems Test Equipment	1800	600	1570	820	
Reliability	400	-	730	-	
Quality Assurance	900	210	1250	520	
Documentation	220	100	520	260	
Launch Operations	200	-	500	300	
Sec. Services & T&L	700	200	1780	950	
TOTALS	27270	7120	21990	9460	65,840
GFE			(14000)	(16000)	(30,000)

Table 5.4. Definition of Subsystem/System Level Tasks

Attitude Control System Module	All effort to design, develop, manufacture, test ACS module hardware, including its structure, harnessing and thermal control.
Power Module and Solar Array	All effort to design, develop, manufacture, test the Power Module and Solar Array Hardware.
Communications & Data Handling Module	All effort to design, develop, manufacture, test C&DH module.
Structure	Structure for general purpose spacecraft, instrument section & transition frame.
Thermal Control	Thermal Control for spacecraft and modules are included in each module or subsystem.
Electrical Distribution	Intermodule harnessing and SCCM included in this task. Other harness included in each module or subsystem.
Interstage Adapter	All effort to design, develop, manufacture, test Interstage Adapter.
Propulsion Module	All effort to design, develop, manufacture, test Propulsion Module hardware.
Wideband Module	All effort to design, develop, manufacture, test module; includes antenna gimbals, tape recorder.
Thematic Mapper Module	All effort to design, develop, manufacture, test Thematic Mapper Module.
MSS Module	All effort to design, develop, manufacture, test MSS Module.
DCS	All effort to design, develop, manufacture, test an ERTS type DCS.
Mechanisms	All effort to design, develop, manufacture, test all S/C mechanisms.
Program Management	Program Management, schedule control, fiscal control, project management.
Systems Engineering	S/C Systems Engineering, Manufacturing support.
Pre-Spacecraft Integration Test	System level "Bench" testing prior to spacecraft testing.
System Integration	Payload subsystems, prototype payload integration and test.
S/C Integration and Assembly	Assembly (only) of spacecraft and payload. Also includes tools, jigs and fixtures.
S/C System Test	S/C Integration and Test (Excluding Assembly) (includes payload)
Systems Test Equipment	Test Ground Station, Special Test equipment, Ground Station O&M.
Reliability	Reliability assurance.
Quality Assurance	Includes Quality Assurance and Configuration Management
Documentation	Data Management
Launch Operations	Launch Support Test Team
Secretarial Service and Travel and Living	

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Table 5.5. EOS Ground Data Handling System Cost Summary
(Dollars X1000)

Subsystem Level	NR	R	Remarks
Operations Control Center	2000	3300	
OCC Operations	-	1000	1 Year Operations
Central Data Processing Facility	7500	7500	
CDPF Operations		2500	1 Year Operations
Network Modifications	1530	-	3 Sites
Low Cost Ground Station	650	190	Assumes On-Board Spacecraft Correction.

Table 5.6. EOS Mission Cost Summaries
(Dollars X1000)

Item	EOS-A NR	EOS-A R	EOS-A' NR	EOS-A' R	EOS-A'' NR	EOS-A'' R	Remarks
Basic Spacecraft	27270	7120	-	7120	27270	7120	
Mission Peculiars	21320	8680	-	8630	21990	9460	Does not include insts.
Spacecraft Totals	58590	15800		15750	49260	16580	
Operations Control Center	2000	3300	-	-	2000	3660	
OCC Operations	-	1000	-	200	-	1200	1 Year Operations
Central Data Proc. Facility	7500	7500	-	-	7500	7500	
CDP Operations	-	2500	-	1000	-	3500	1 Year Operations
Network Modifications	1530	-	-	-	1530	-	
Additional Receiving Site Equip.	-	-	-	-	600	-	
Ground Sys. Totals	11030	14300	-	1200	11630	15860	
Launch Vehicle	-	6000	-	6000	-	8000	
Sub-Totals	59620	36100	-	22950	60890	40440	
Total Mission Cost (Less Instruments)	118670				101330		2 Spacecraft vs 1

is launched with a payload of two MSS's and 1 TM rather than two spacecraft to perform the same mission.

Figure 5.1 presents the time phasing of costs for the EOS-A'' mission, predicated on the summary schedule shown in Figure 5-2.

Based upon the myriad design/cost trade studies performed during the EOS Definition Study Program and those completed previously, the Space Division of the General Electric Company is convinced that the Aerospace Team can effectively lower the cost of space developments. The standardization concept and the repeated use of a flexible modularized basic spacecraft offers a clear-cut way to eliminate most of the development costs for succeeding users.

By using the standardization approach and by reshaping management practices, significant cost savings will be realized on the EOS Program. EOS, because of the many missions involved, is a logical program to initiate a concerted effort to design, develop and manufacture a series of standard basic spacecraft which can be effectively utilized to provide the vehicle by which many developmental/operational payloads can be carried into earth orbit.

The program concept is sound and the potential benefits great. Low-cost principles, handled properly on the EOS program, will provide an effective tool for science or applications missions.

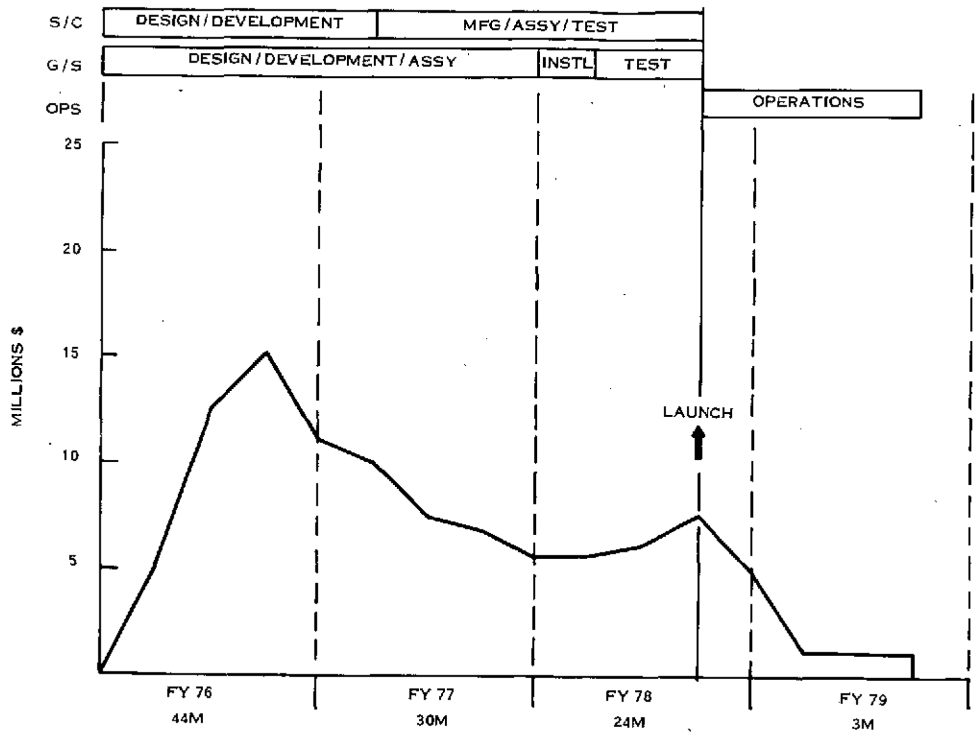

Figure 5.1. EOS-A" Expenditures by Quarter

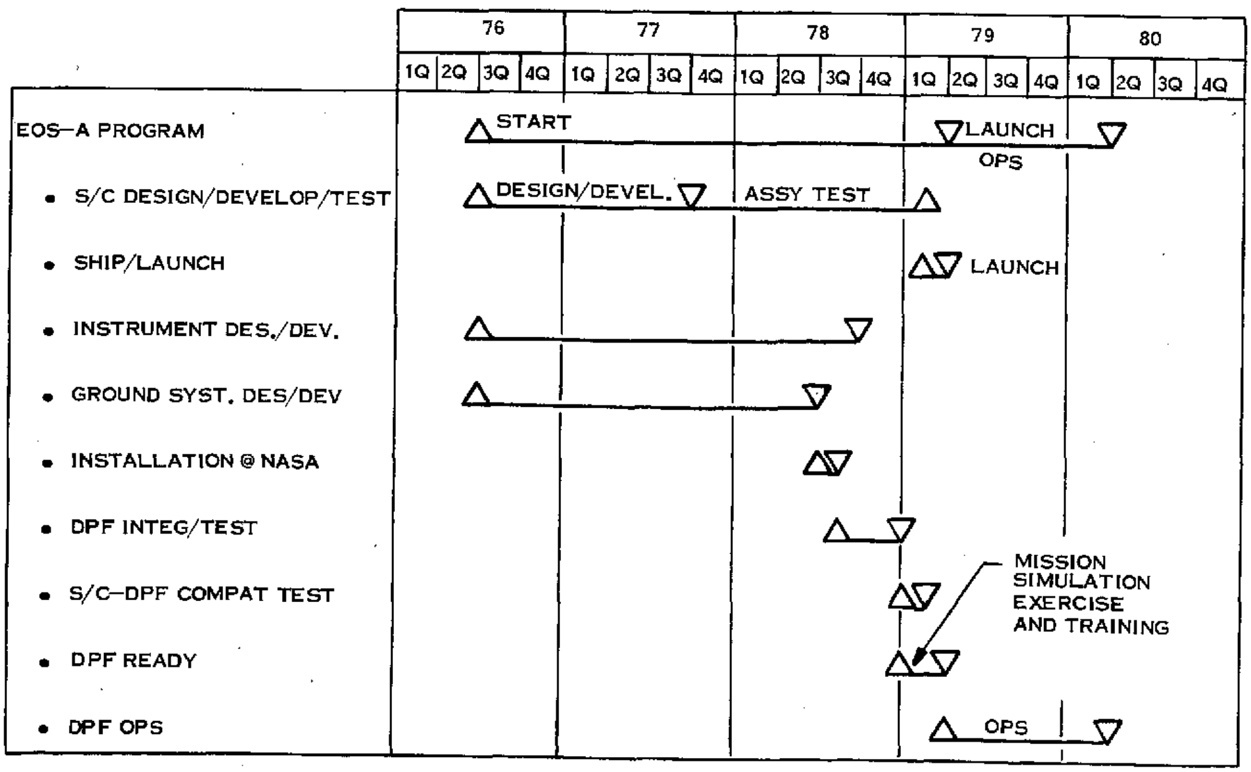

Figure 5.2. EOS-A" Summary Schedule